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Preface

Animal welfare began to emerge as a scientific discipline in the 1960s, and there is now a large body of published research addressing a range of fundamental and applied topics. However, the field is currently in a stage of transition, with an increasing emphasis on translating the knowledge that has been gained into 'real world' improvements. This is necessitating new and ever more sophisticated research approaches, including collection of more complex data with an increasing focus on solutions, the development and use of new research methodologies and technologies, and integration of information across different disciplines. It also requires enhancing communication and collaboration among diverse stakeholders, as well as developing science-based approaches for setting 'best practice' standards and on-site welfare assessments to help ensure public confidence.

The five books in this series provide overviews of key scientific approaches to assessing and improving the welfare of farm animals and address how that science can be translated into practice. The books are not meant to provide a comprehensive overview, but instead focus on selected 'hot topics' and emerging issues for cattle, pigs, poultry and sheep (as well as the overarching issue of linking animal welfare science and practice). Advances and challenges in these areas are presented in each book in the form of an integrated collection of focused review chapters written by top experts in the field. The emphasis is not just on discussing problems, but on identifying methods for mitigating those problems and the knowledge gaps that remain to be filled.

Although the topic reviewed in the cattle, pig, poultry and sheep books are tailored to those most important for the particular species, all of the books include an overview of production systems and discussion of the most pressing animal welfare challenges and important advances associated with those systems from the perspectives of normal and abnormal behavior, animal health, and pain management. Emphasis is placed on both management and genetic approaches to improving welfare, as well as on emerging scientific tools for investigating questions about the welfare of that species. As relevant, the books also include reviews on human−animal interactions and transport and/or slaughter. Finally, practical tools for in situ (on the farm, during transport, or at the slaughter facility) assessment of welfare are presented. The reviews in the overview volume focus on animal welfare in the context of agricultural sustainability, and also address how science can be translated into practice taking into account ethical views, social developments, and the emergence of global standards.

The topics covered by these books are highly relevant to stakeholders interested in the current and future developments of farm animal welfare policies, including farmers, food industry, retailers, and policy makers as well as researchers and veterinary practitioners. The editors hope they serve not only to help improve farm animal welfare but to encourage discussion about future directions and priorities in the field.

Joy Mench
Series Editor

Introduction

Welfare problems in contemporary intensive pig husbandry are manifold. Nevertheless, several major clusters of issues can be identified that encompass most of the serious challenges. The first gridlocked complex relates to pig reproduction and comprises housing of sows around farrowing and during lactation together with early piglet mortality. The second complex of problems arises in pig interactions with the barren physical environment. The dearth or lack of bedding, manipulable material and fibre-rich feed across all pig categories causes serious welfare problems such as tail biting, stereotypic behaviours and motivational frustration. The third cluster is in the social domain and includes mutual aggression and associated problems in pen-housed pigs. The fourth complex resides in human care and interactions with the pigs. The rates of housing-related health problems are uncomfortably high in intensive pig husbandry and due to practical constraints it is difficult to provide sufficient individualised care to the animals, especially to vulnerable individuals such as the weak, sick, injured, behaviourally disturbed and socially harassed pigs as well as pigs in transport and at the abbatoir. Finally, invasive procedures are routinely performed on wide classes of pigs without pain mitigation. The aim of this book is to show how pig welfare could be advanced. Therefore it is appropriate to present the five clusters in their positive morphs as *five pig welfare aspirations*:

1. movement freedom for farrowing and lactating sows coupled with reduced piglet mortality;
2. provision of biologically important materials for pig nest-building, exploration, foraging and feeding;
3. social life matching the pigs' motivation and capabilities;
4. informed and individualised care of pigs, especially those with health problems and in other need;
5. no painful body alterations for pigs.

What hinders faster progress towards these goals? How can we use the available knowledge to navigate the trade-offs in pig welfare? What further research is needed to untie the current gridlocks? What are the promising alleys for cooperation between stakeholders in the field of pig welfare? The 16 chapters of this book written by leading experts provide up-to-date knowledge about the most pressing areas of pig welfare, highlight the dynamic research directions and discuss practical strategies for a common effort to improve pig welfare in the framework of profitable and sustainable pig husbandry.

The book content

The book is divided into two sections. Part I consists of 10 chapters that systematically review major pig welfare hot spots throughout the pig production cycle from farrowing and birth until to slaughter. Part II then highlights six prominent emerging topics in pig welfare that apply across all the pig age and sex categories.

Part I opens with an introductory chapter by Lene Juul Pedersen that overviews the production cycle of pigs, highlighting *the main welfare challenges in commercial pig production systems* and outlines possible improvements on the background of the EU welfare regulation. Pedersen concludes that majority of the problems are inherently related to the housing and management applied as well as to breeding for intensive production traits. As these factors are not easily changed without costs, suggestions for changes are often met by resistance from the industry. Nevertheless, as Pedersen stresses, changes that improve welfare may bring profit in the long term through improved health, longevity and productivity of pigs with high welfare.

The following three chapters of Part I then review pig welfare hot spots during farrowing, piglet birth and early ontogeny. In two chapters, Emma Baxter and her co-authors address the entangled welfare complexes of *sow welfare during farrowing and lactation* and of *piglet mortality and morbidity*. Baxter et al. show that it is not easy to resolve the ‘triangle of needs’ of the sow, her piglets and the farmer. They highlight the shortcomings of the current selection programmes that overlook several costs of the increased productivity and are thus pushing the triangle into trade-offs that are ever more difficult to negotiate. Yet Baxter et al. posit that it is possible to create systems that work with the biological needs of the animals involved, rather than battling against them. For this, it is necessary to understand the biology—housing interface so that systems capable of mitigating the challenges brought by intensive breeding strategies could be designed. Furthermore, balance needs to be achieved in breeding indices between traits giving short term productivity and traits that improve welfare and longevity of the sows and as well as promote more robust piglets. As Helena Telkänranta and Sandra Edwards discuss in the next chapter, *early physical and social environment of piglets* has been documented to contribute to development of piglet abnormal behaviours such as tail biting, belly nosing and increased aggression. Yet more research is needed to better understand the neurobiological effects of different enrichment materials and stimuli during sensitive periods in early ontogeny on the developing piglet brain and mind.

Four chapters address welfare problems of growing and adult pigs. *Tail biting*, a serious problem in group housed pigs that carries with it the habit of ‘preventive’ tail docking in almost all intensively housed pigs in the world, is analysed by Anna Valros. Valros assesses the known chronic and acute risk factors and presents the possible risk reduction strategies in terms of genetics, environmental enrichment and detection of outbreaks. Moreover, she underscores the need to develop a more holistic ethical model that would weigh the welfare gravity of routine tail-docking against the tail biting risks, especially as the existence of pigs with long tails may result in pressure for improvements in management that reduce the stress experienced by all the pigs. Marc Bracke in the next chapter addresses the related topic of *manipulable materials for pigs*. Despite the fact that provision of manipulable material to pigs is obligatory in EU, what counts as proper material for that purpose remains largely unresolved. Bracke presents a detailed account of development, testing and adoption of a specific enrichment device, namely a branched chain design, in the Netherlands. In the following chapter, Richard D'Eath and co-authors turn to the issue of *subjective hunger in pregnant sows* in the typical situation with no foraging substrate and low level of dietary fibre. The authors provide highly informative overview of the chemical types of fibre and their effects on satiation and digestive physiology. Their conclusion is that soluble fermentable fibre or resistant starch have particularly beneficial effects because the pig hindgut is capable of fermenting these types of fibre into short-chain fatty acids, thus prolonging the satiety effects and contributing positively to the energy balance of the feeding process. The next chapter by Megan Verdon and Jean-Loup Rault moves on to the problem of *aggression in group housed sows and fattening pigs*. Verdon and Rault distinguish aggression following mixing, from aggression once a hierarchy has been formed, and thoroughly review the factors affecting these two types of aggression. The two final chapters in Part I address *handling and transport of pigs* to slaughter (by Luigi Faucitano and Sébastien Goumon) and the *slaughter process* itself (by Antonio Velarde and Antoni Dalmau), including aspects such as pre-slaughter feed withdrawal, loading of animals, truck design, holding of pigs at the slaughterhouse (lairage) and stunning methods.

Part II of the book consists of six chapters that focus on fast-progressing research topics in pig welfare. In the chapter on *pain in pigs*, Mette Herskin and Pierpaolo Di Giminiani review evidence for causes of different pain types in pigs and analyse the possibilities for quantitative indicators of pain states. They underscore the current low level of knowledge of porcine pain and call for targeted research in order to protect pigs from this negative affective state. The next chapter by Déborah Temple and co-authors reviews the currently available *on-farm and post mortem health assessment methods*. The chapter documents that the methods are in constant evolution, thus increasing the collection of validated and practicable pig health indicators. *Pig—human interactions* are the topic of the chapter by Céline Tallet and co-workers. The authors discuss the role of pig sensory, learning and social capacities in the development of pig fear or trust in humans. They stress that education and training of stockpersons is needed to promote knowledge-based care of everyday human—pig interaction that will impact positively on animal welfare, production and human work satisfaction. The chapter by Simon Turner and co-authors presents the state of art in *breeding for pig welfare*. The authors use three examples of selective breeding for welfare traits — neonatal survival, diminished aggressiveness towards pen mates and reduced tail biting — to illustrate the progress. They foresee that new techniques and genetic methodologies will expand the range of welfare traits that selection can be exerted upon. Furthermore they posit that such breeding alongside continued efforts to establish feasible management interventions may help to mitigate some of the most difficult and significant pig welfare challenges. The penultimate chapter by Alistair Lawrence and co-authors covers the intensely debated topic of *positive pig welfare*. The chapter reviews several published frameworks for positive welfare that draw from human positive psychology and the concept of quality of life. So far, positive welfare in pigs has been rarely measured on farm. Nevertheless, the authors make the case that a focus on positive welfare could open new insights into positive emotional states and instigate changes across the human supply chain in favour of improved pig welfare. The final chapter of the book by Jeremy Marchant-Forde and Mette Herskin looks at *pigs as laboratory animals*. With the pig becoming an increasingly popular laboratory animal, new welfare issues arise such as lack of validated methodology to monitor and manage pig pain and barren individual housing resulting from an emphasis on hygiene and needs of the caretaker. Specialised research on pig welfare in laboratory settings is needed, including the role of positive reinforcement training in order to facilitate experimental procedures.

A wish for the book

This book highlights the dynamic advances that have been made in pig welfare, mainly in the last two decades. Group housing for pregnant sows has replaced individual stalls in Europe and elsewhere; the need for practicable yet biologically meaningful environmental enrichment for pigs is being recognised; free housing for farrowing and lactating sows is being investigated, coupled with efforts to reduce piglet mortality; efficient methods to monitor pig health and provide informed and individualised care are getting available; and possible ways to reduce and ultimately abolish painful body alterations are being explored. Despite this progress, many welfare issues remain gridlocked. Further advances need to negotiate many obstacles including tight economical margins, inherent trade-offs and different interests among stakeholders. Science-based knowledge and innovative solutions at the interfaces between biology, engineering, information technology and humanities are the best tools to make improvements in pig welfare a reality in the years to come. It is a wish of the editor and the author team that this book will serve as a useful reference and inspiration in the common effort to improve pig welfare worldwide.

Marek Špinka
August 2017

Overview of commercial pig production systems and their main welfare challenges

1

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1.1 Introduction

Since the 1960s, the commercial pig production in industrialised developed countries has undertaken a dramatic change, from small family-run farms to larger industrialised production units with a private owner and several/many employees. These changes have led to a shift from extensive housing systems with a low degree of confinement and high labour input, to economically efficient units with low labour input, low space allowance, a high degree of confinement, and use of slatted floor systems with little or none environmental enrichment. In addition, the management has changed towards the use of automated feeding and climate control systems, less surveillance of individuals, and use of early weaning and artificial insemination methodologies.

Along with these changes, there has been an arising awareness of animal welfare issues related to the use of industrialised production methods amongst consumers, policy makers and retailers. Therefore, today's pig production in the EU, which is responsible for approximately 25% of the world's pig production in 2014 (FAO), is to some extent controlled by welfare legislation setting down minimum standards for acceptable welfare. Similar welfare regulations are now emerging in other pig-producing countries, such as the United States, Canada and Australia.

Despite the welfare legislation, the pig industry still faces major welfare challenges. These are not easily solved under economically tight production conditions, and an increasing demand on the industry to reduce the environmental impact of the pig production. To be able to improve pig welfare under these conditions, there is an urgent need for an open-minded and obligating collaboration between animal scientists, environmental scientists, companies that develop equipment for the pig industry, as well as stakeholders from both the industry and animal welfare organisation. The aim of this chapter is to: (1) give an overview of productions systems used in the industrialised pig production of bulk meat; (2) summarise how housing and management within the EU countries are affected by the EU Directives; and (3) describe the causes for major welfare problems still remaining and possible ways forward to solve them.

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1.2 Production cycle of pigs

Breeding of female pigs is organised into a three-step system consisting of breeding herds, multiplier herds, and production herds. In the breeding herds, purebred sows and boars are selected and bred according to a specific selection criteria defined by the company's strategy. The purebred sows are not used for production of rearing pigs but female offspring are used in multiplier herds where crossbreeds are produced and sold to production herds where the rearing pigs are produced. Our discussion here is only concerned with the rearing of sows and pigs in production herds.

To understand the different welfare challenges in the production herds, a brief introduction to the production cycle of pigs are given below. The cycle divides the pig production into stages, each representing different housing systems, different welfare regulation and welfare problems. The different units may of course not be representative for pig production throughout the world, but cover the majority of the somewhat standardised bulk pig production.

1.2.1 The mating unit

Conception of a production pig usually takes place by artificial insemination of a production sow. Prior to insemination, sows are placed in a specific *mating unit* after weaning of the previous litter. Usually sows come into oestrus within 4–6 days after weaning. Oestrus lasts 2–3 days, and during this period sows are artificially inseminated 2–3 times while given contact (physically and/or visually) with a mature boar. The fertilisation takes place within 24 hours after insemination, while the attachment of the embryo to the uterus does not occur until 7–14 days after. During this period, the survival and attachment of the embryos are sensitive to imbalances. Therefore, any disturbances during this period may result in a low litter size or in lack of conception, resulting in the sow returning to oestrus after 3 weeks. Sows are typically housed in the mating unit from the time of weaning of the previous litter until 4 weeks after, or until the last insemination has taken place (when the oestrus symptoms have ceased). Sows are kept in the mating unit until 4 weeks after weaning to confirm that they are pregnant. This can easily be done in the mating unit using boar stimulation, while observing if sows return to oestrus 21 days after insemination. In addition, keeping sows in the mating unit until 4 weeks after insemination will ensure that sows are not exposed to disturbances caused by a change in environment during the sensitive period of attachment of the embryos to the uterus.

In herds that supply their own production sows, female pigs are selected at a young age to replace culled production sows. The selected female pigs will be moved at puberty to the mating unit to be inseminated, usually in their second or third oestrus. Other herds may purchase crossbreed female pigs from the multiplier herds usually before puberty. When pregnant, the young female pigs are termed *gilts* until they give birth to their first litter. From that time, they are called sows.

A sow is usually culled after 4–6 litters; some will only produce one litter while a few will get more (typically not more than 8–10 litters). When culled they will be replaced by new gilts.

1.2.2 The gestation unit

After the mating unit, the sows are moved to the so-called *gestation unit* where they ideally stay until 5–7 days prior to parturition.

1.2.3 The farrowing unit

Some days before birth is expected, farrowing sows are moved to the *farrowing unit*. In this unit sows give birth to a litter of 10–25 piglets. They stay in the unit during farrowing and until artificial weaning of the litter, which typically takes place between 2 and 5 weeks after farrowing. The time of weaning may be controlled by welfare regulation (see later in the chapter). As soon as the piglets are weaned by moving them away from the sow, she will return to the mating unit to start a new reproductive cycle. Otherwise, she may at this point be culled due to age, disease, reproductive problems or poor maternal performance. In countries using high prolific sow lines, the litters may be too large for the mother sow to nurse by herself. This has led to the use of so-called nurse sows that first give birth and nurse their own offspring for 7–21 days and then are given 2–7-day-old surplus piglets from another sow to nurse until weaned. This system is routinely used, for example in Denmark, where the average litter size has reached more than 17 piglets due to intensive selection for large litter size. These nurse sows will stay for a prolonged period in the farrowing unit.

1.2.4 The weaner unit

At weaning, the piglets will typically be moved to a *weaner unit* and are now called *weaners*. In the weaner unit, the climate and feed system needs to be customised to meet the physical and nutritional requirements of early weaned pigs.

1.2.5 The rearing unit

When weaners are around 25–30 kg they are moved to the *rearing unit* where they stay until slaughter. They are now called *rearing* pigs (term used in this chapter) or fattening pigs, finishers or slaughter pigs. The weight at slaughter is depending on the production method and condition, but will typically vary between 80 and 120 kg. At slaughter the pigs are around 5–8 months old. The life of production sows and weaner/rearing pigs is illustrated in Fig. 1.1.

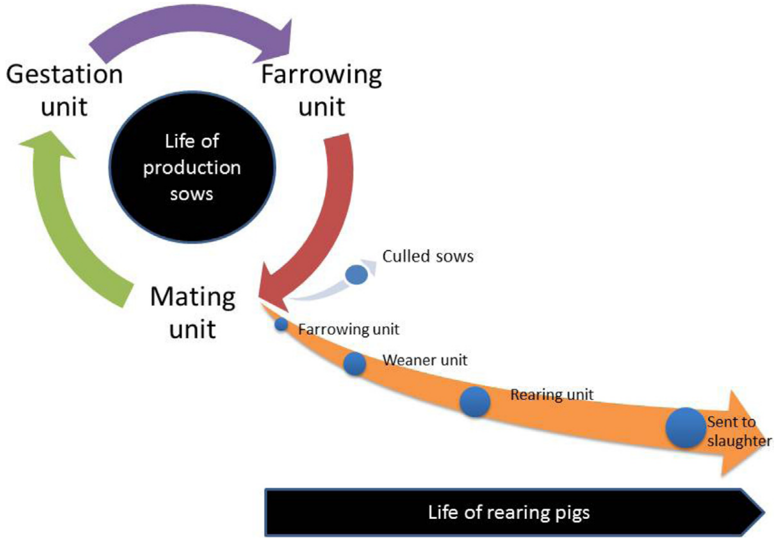

Figure 1.1 Schematic illustration of life of production sows and rearing pigs.

1.3 Housing systems and EU welfare regulation

As described above, each production stage typically takes place either in different units of a farm, or on another farm specialised in the specific production period (e.g., sow herds or pig rearing herds). In both cases, the housing and management are customised to fit the specific events taking place in each stage. In the following material we will focus on describing some examples of the most commonly used housing systems seen on larger industrialised farms producing the majority of the pig meat in Europe for the bulk market. Similar systems are also found in other parts of the world where industrialised pig production takes place, such as China, North America and Brazil. In the EU countries, welfare legislation set minimum standards for the production of pigs, with specific regulations for each stage in the production life. In 1991, the *Council Directive 91/630/EEC laying down minimum standards for the protection of pigs* was adopted. The Directive contains minimum standards for pigs, minimum space allowances for weaners, breeding sows and rearing pigs, and general requirements for housing, equipment, surveillance, feed and water are described. In an appendix, more specific requirements for each category of pigs (boars, sows and gilt, suckling piglets, weaners and rearing pigs) are described. Individual EU countries can introduce higher legislative standards than these agreed on amongst the EU countries. The Directive was changed by *Council Directive 2001/88/EEC*. The changes primarily regard specific welfare improvements for sows, such as minimum standards for space allowances, floors and specific requirements for group housing of sows during the majority of the gestation period. In addition, a requirement for high fibre food for sows and gilts was given. Further, the EU *Council Directive 2001/93/EC* extended the previous pig welfare

Directive highlighting, amongst other things, the importance of environmental enrichment for pigs, and specific regulations concerning tail docking and castration of pigs. The directive was consolidated by the *Council Directive 2008/120/EC*.

Both outside and within EU, welfare standards may also be set by retailers of welfare label meat. These may vary considerably amongst countries and labelling requirements, but may be important for the improvement of welfare worldwide.

1.3.1 Mating unit

In the mating unit, sows can be individually confined in stalls (Fig. 1.2A), housed individually in pens (Fig. 1.2B) or grouped in smaller or larger groups (Fig. 1.2C). The *Council Directive 2001/88/EC* does not require group housing of sows and gilts during the period from weaning to 4 weeks after service. However, there are several European countries that require group housing either during the entire period (Sweden, Norway), or from service until 4 weeks after (The Netherlands, Denmark). In addition, group housing has been common practice on many farms in the United Kingdom and in countries exporting to United Kingdom due to the requirements under specific label production. Group housing in the mating unit is often designed with an open pen area and free access to individual feeding/insemination stalls. Access to the feeding stalls allows individual feeding of the sows, as

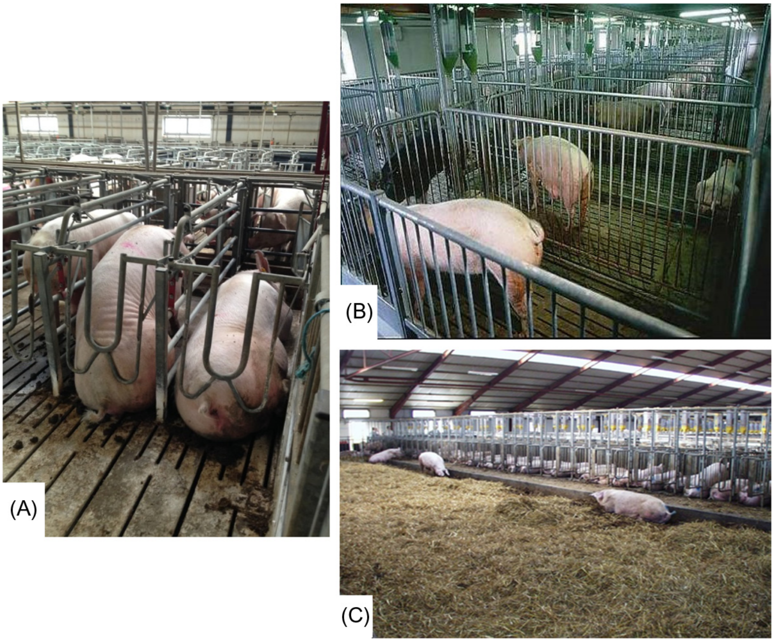

Figure 1.2 Examples of housing systems for sows in the mating unit: (A) stall housing with permanent confinement, (B) individual housing in pens, (C) group housing with free access stalls and deep litter.

well as a protected working environment during oestrus control and insemination. The stalls can also protect subordinate sows from aggression injuries. In the open area, the floor needs to be free of slippery areas to avoid leg injuries when sows mount each other during oestrus. Part of the floor is usually solid or drained, and some straw bedding or even deep litter are often used to prevent slipperiness. Sows may stay in the mating unit until 4 weeks after service for oestrus control or they are moved to the gestation unit right after service. In the traditional stall housing, sows are permanently confined in stalls without the ability to turn around.

1.3.2 Gestation unit

The *Council Directive 2001/88/EC* requires that sows and gilts shall be kept in groups during a period from 4 weeks after service to 1 week before expected time of farrowing. The space allowance of an unobstructed floor area should be at least 2.25 m^2 for sows and 1.64 m^2 for gilts. Therefore, group housing is the practice today in all EU countries, whereas stall housing (Fig. 1.3A) is still seen in many countries outside EU. There are several types of group housing, allowing either protected individual feeding for each sow or unprotected group feeding. In all systems,

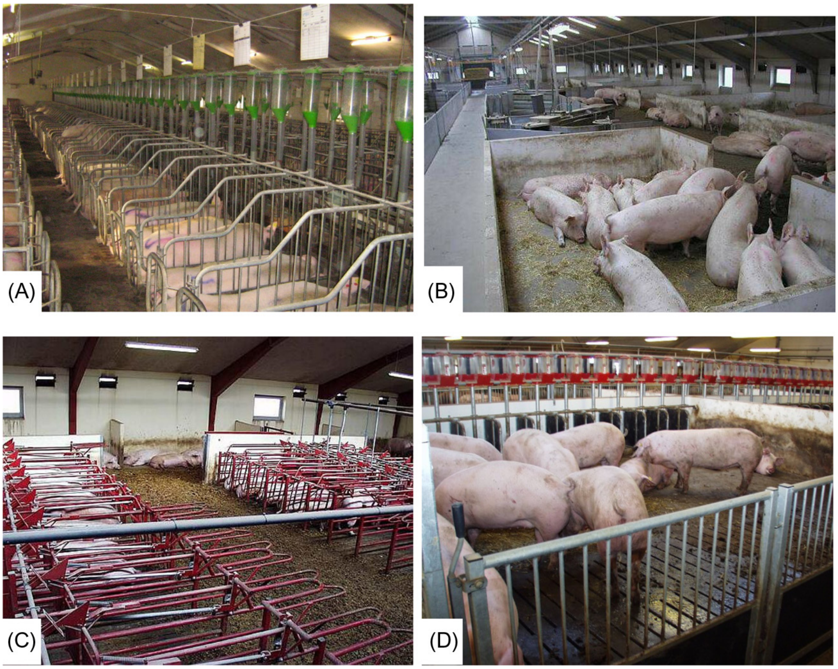

Figure 1.3 Examples of common group housing systems for gestating sows: (A) stall housing with permanent confinement, (B) pens with Electronic Sow Feeding (EFS) and separated areas for resting, (C) group pens with free access feeding stalls and a bedded t-shaped resting area, (D) group housing with partly unprotected feeding.

parts of the floor shall be concrete or drained according to the Directive's requirements. An example of a common group housing with protected individual feeding are Electronic Sow Feeding (ESF) systems (Fig. 1.3B). These systems consist of a communal area, often divided into an activity and dunging area around the feeding station with slatted floor and resting areas divided into smaller separated areas with concrete floor and possibility for straw bedding. The ESF station can feed up to 70 sows per station and therefore, this feeding system is often used with larger groups. A chip is attached to the ear of the sows, allowing them access to the feeding station where they are given a certain amount of daily food according to their body condition. Sows cannot eat simultaneously and therefore there is a risk that dominant sows can block the access to the feeding station and prevent subordinates from access. However, the ESF station protects the sow from aggression during eating and gives the farmer many possibilities for management of the individuals. It demands high management skills and extra surveillance to ensure that all sows and gilts learn to use the system, and that all sows on a daily basis get access to the feeding station and eat their ration.

Pens with free access to feeding/resting stalls are also commonly used (Fig. 1.3C). In these systems sows are fed simultaneously once or twice daily and aggression over access to the feeder is therefore limited to a relatively short period of the day. Sows are protected against aggression during eating and individual feed allocation is therefore possible, although it demands extra work compared to Electronic Sow Feeding. Often there are two rows of feeding stalls (one stall per sow) and a communal area in between the stalls.

A third type of group housing systems consists of an open pen area with partly slatted and partly solid/drained floor. Sows are either floor-fed or fed in partly separated troughs simultaneously once or twice daily. Thus, also in this system aggression during feeding is limited to relative short periods of the day. However, sows are not protected during eating, and if the available space is limited and feed is not bulky, there is a high risk of aggression to an extent where dominant sows can prevent subordinate access to the food (Fig. 1.3D).

1.3.3 Farrowing unit

The far most common housing of sows during the periparturient period and during lactation is the farrowing crate (Fig. 1.4A). The farrowing crate consists of a pen (typically between 3.5 and 4.5 m^2) within which bars are installed to prevent the sow from turning around. Outside the bars, there is space for piglets. According to *Council Directive 2001/93/EC: 'a part of the total floor, sufficient to allow the animal to rest together at the same time, must be solid or covered with a mat, or be littered with straw...'*. Therefore, some pen types have a roof-covered creep area with solid floor for the piglets situated in a corner or along the side of the pen (see Fig. 1.4A, upper left corner). Other pens just have a mat or a plate (eventually heated) along one side of the pen for piglets to rest on. There is no specific space allowance for farrowing pens except the general term in the *Council Directive 91/630/EEC* stating that: '*the accommodation for pigs must be*

Figure 1.4 Examples of farrowing pens: (A) farrowing crate with permanent confinement and a covered heated piglets corner, (B) farrowing pens for loose-housed sows with a covered and heated piglet corner.

constructed in such a way as to allow each pig to lie down, rest and stand up without difficulties'. In addition, there are general terms stating that: '*an unobstructed area behind the sow or gilt must be available for the ease of natural or assisted farrowing*'. Finally the *Council Directive 2008/120/EC* states that: '*in the week before the expected farrowing time, sows and gilts must be given suitable nesting material in sufficient quantity unless it is not technically feasible for the slurry system used in the establishment*'. Besides these regulations, piglets: '*must have sufficient space to be able to suckle without difficulties*'.

Meanwhile, as for the mating unit, there are a few European countries that request that farrowing sows shall not be kept in crates (Sweden, Norway and Switzerland). In these countries, sows are kept in pens without crates. These are not as standardised as the farrowing crate. An example of a farrowing pen developed in Denmark is shown in Fig. 1.4B. Also, some welfare labels, such as organic production and outdoor production require non-crate systems for the farrowing sows. Particularly in the United Kingdom, these are widespread due to a large population of outdoor-kept sows.

1.3.4 Weaner unit

After weaning, at an age of 2−5 weeks, most piglets are moved immediately to a weaner unit. In the EU according to *Council Directive 2008/120/EC*: '*no piglet shall be weaned from the sow less than 28 days of age*'. Piglets may be weaned as early as 21 days of age but only allowed if: '*they are moved into specialized housing which are emptied and thoroughly cleaned*'. Due to the use of early weaning, weaned pigs need a highly controlled climate with supplementary heating and specialised feed. According to Broom et al. (2007) the majority of weaners in EU are either housed in fully or partly slatted pens, without or with very restricted bedding. Typically, pigs

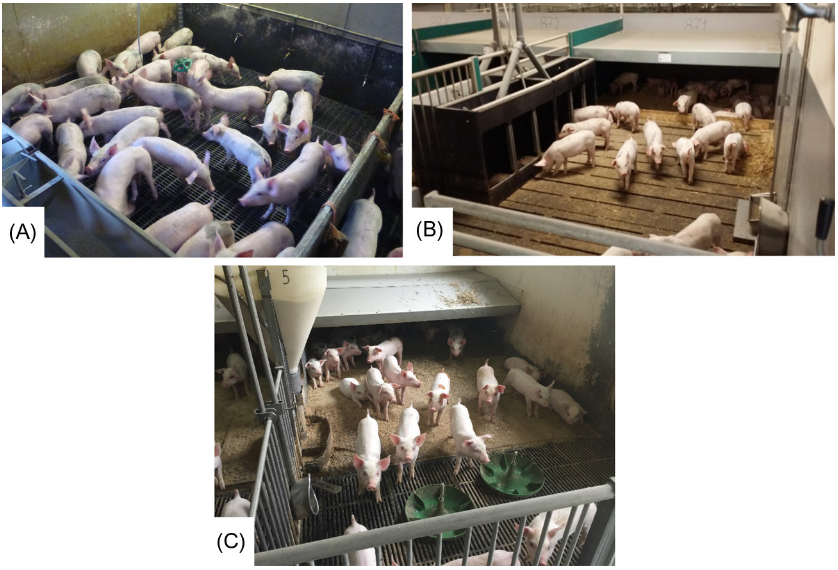

Figure 1.5 Examples of weaner pens: (A) fully slatted pens in climate controlled rooms, (B and C) two-climate pens with partly solid floor and a roof-covered area with straw and sawdust.
Source: Copyright (B) M.L.V. Larsen.

are regrouped at weaning and may stay in groups of 10−40 pigs. They are either fed *ad libitum* (dry feed) or fed a restricted liquid feed. The housing is typically in climate controlled buildings with fully slatted floors (Fig. 1.5A), or they are constructed with two-climate zones (Fig. 1.5B and C). In the two-climate system, the pen is typically designed with one-third of the pen as a lying area, where the floor is either solid or drained. The floor can be covered with straw/sawdust and/or covered by a rubber mat or heated to obtain a thermal comfortable area. The lying area is covered by a roof to obtain a thermal comfort zone for resting. The other part of the pen is typically a slatted floor area where temperature can be kept lower. The *Council Directive 2001/88/EC* states the space allowance per pigs for 10, 20 and 30 kg pigs is 0.15, 0.2 and 0.30 m^2, respectively. Also, it states that the slat width of concrete slatted floors shall be less than 14 mm for weaners.

1.3.5 Rearing unit

The most typical housing system for rearing pigs is the fully slatted pens (Fig. 1.6A and B) or partly slatted pens (Fig. 1.6C), with either dry feed *ad libitum* or liquid feed. Due to the use of liquid slurry systems being the predominant manure handling system, pens are rarely bedded and none or rather restricted amount of straw or similar materials are given to the pigs. The space allowance at the end of the rearing period depends on the slaughter weight but according to *Council Directive*

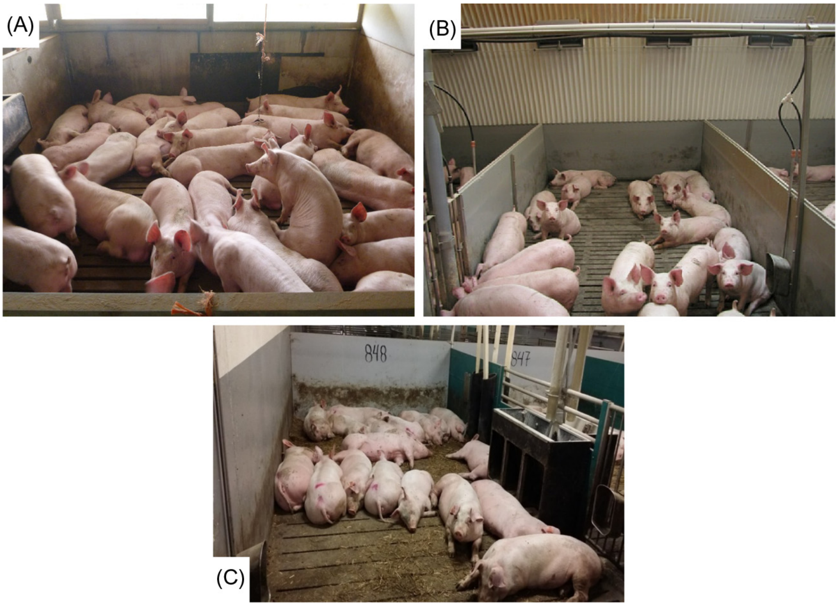

Figure 1.6 Examples of rearing pens. (A and B) Pens with drained and slatted floor, (C) pens with partly solid floor and possibility for straw allocation.
Source: Copyright (*C*) M.L.V. Larsen.

2001/88/EC pigs shall be given at least 0.65 m^2 per pig up to a live weight of 110 kg. Partly slatted floor pens may allow for some bedding/straw to be given but may also require more space per pig than fully slatted pens, for pigs to keep the solid part clean.

1.4 Welfare challenges and possible improvements

Despite the EU welfare Directives laying down minimum standards for the protection of pigs, major welfare problems still exist in each of the units described above, both within and outside the EU countries. The following is an overview of some of the major welfare challenges for the different categories of pigs with suggestions for ways forward.

1.4.1 The mating unit

Sows are moved to the mating unit when their litter is weaned. Signs of pro-oestrus are evident a few days after weaning, shown as increased activity, restlessness and a strong motivation for social contact (Pedersen, 2007). During the period of oestrus, the normal circadian rhythm in activity is completely abolished, and sows remain active throughout night and day with bouts of activity alternating with bouts of resting. When active and in groups, they sniff, push and mount each other continuously, and if a boar is present they search towards the boar pen. Restriction of movements and social contact during this period therefore strongly conflicts with their endogeneous driven motivation, resulting in frustration that compromises their welfare. In addition, at the time of weaning sows milk production and feed intake peaks (Theil et al., 2004) and thus, heat production is also high. Confinement in stalls prevents sows from thermoregulation by posture changes and wallowing; both being their predominant means for heat regulation. Besides, the more general welfare consequences of stall housing is still present such as a stress reaction to close confinement (Barnett et al., 1985; Friend et al., 1988), impaired getting up and down movements (Taylor et al., 1988; Marchant and Broom, 1996b), reduced cardiovascular fitness (Marchant et al., 1997), reduced bone strength (Marchant and Broom, 1996a) and increased morbidity (Backstrom et al., 1994). Also, confinement in conjunction with feed restriction has been suggested to be involved in the development of oral stereotypies (Lawrence and Terlouw, 1993; Terlouw et al., 1993).

The obvious solution to these welfare problems is group housing. Group housing may allow sows to express their natural behaviour during oestrus, to thermoregulate by changing lying posture and position and by wallowing. Besides, grouping immediately after weaning constitutes an optimal time for grouping due to increased social acceptance around oestrus (Pedersen, 2007). However, to achieve high welfare in a group housing system in the mating unit, sufficient space needs to be given; not only to ensure space to establish and maintain a stable dominance hierarchy, but also to ensures space for high levels of activity, social contact and mounting behaviour during oestrus. Without enough space, problems with maintenance of a stable dominance hierarchy may occur, eventually resulting in reduced reproduction (reviewed by Turner et al., 2002; Spoolder et al., 2009). The space allowance given for gestating sows in the *Council Directive 2001/88/EC* of 2.25 m^2 per sow barely meets the static space used for lateral lying (Baxter, 1992). Due to the increased activity during oestrus, sows need more space in this period than during gestation. Fighting can be estimated to take up approximately 3.8 m^2 for a 200 kg sow (Baxter, 1992) and similar space or more space is needed when sows are engaged in sexual behaviour. The intensive mounting behaviour, particularly shown by larger and dominant sows towards smaller and subordinate sows (Pedersen, 2007), put extra demands on high quality of the floors. Leg injuries may easily occur if the floor is slippery (Spoolder et al., 2009). Provision of straw or even deep straw bedding may be one solution to prevent lesions (Holmgren et al., 1998), although deep straw bedding may be problematic under hot conditions as composting may occur and prevent sows from cooling down. To further develop the group housing system in the mating unit, research needs to focus on methods to increase space during grouping and oestrus and on improving floor quality to prevent slipperiness and leg injuries.

1.4.2 The gestation unit

Due to the *Council Directive 2001/88/EEC* the EU countries have changed during the last years from predominantly using stall housing to now predominantly using group housing. This change has removed a major constraint to good welfare. Group housing allows sows to move and be active whenever motivated to do so. They can forage, have social contact and thermoregulate behaviourally by postures, wallowing and by choosing different zones in the pen with different temperature. They can also spatially separate defaecating, eating and resting according to their biology. However, to obtain good welfare in a group housing system, it is necessary that the pen design and management allow the sows to build and maintain a stable social hierarchy in order to avoid excessive aggression. A number of important pen design and management factors needs to be considered which strongly affects the space needed in the pen. Thus, space is not only a matter of square metre per sows, as defined in the EU Directive. The need for space highly depends on the stability of the social hierarchy. Thus, factors increasing the level of aggression also increase the need for space. Therefore, factors such as the stability of the social group (e.g., sows may show more aggression in dynamic groups than in stable groups), the quality of the space (e.g., a solid floor area as opposed to a slatted area can be a limited resource), the total available space (e.g., in larger groups there are more total space allowing for escape zones), whether or not there are narrow passages/bottlenecks around resources (e.g., even with a high space allowance, high aggression can be seen if bottlenecks exists), type of feeding system (less need for space with protected feeding than with unprotected feeding), etc. All these aspects affect the space that is required (reviewed by Spoolder et al., 2009; Bench et al., 2013b; Verdon et al., 2015).

If several risk factors for high level of aggression are present simultaneously, space needs to be larger to avoid lesions, poor body conditions and culling of sows, all being well-known consequences of high level of aggression. A high focus on good pen design for group housed sows, taking the above elements into consideration, is therefore important to achieve high welfare in a group housing system.

In addition to the many features related to pen design that may constitute a threat to sow welfare in group housing systems, another important welfare issue is the feeding with a restricted concentrated diet to avoid obesity. This feeding regime results in behavioural problems indicative of hunger (reviewed by Meunier-Salaun et al., 2001). Signs of hunger occur already a few hours after feeding even if part of the concentrated diet is exchanged with more fibrous feed stuffs such as dry pelleted sugar beets (Jensen et al., 2012). When sows are housed in groups, hunger will provoke aggression over food and thus lead to increased risk of skin lesion and leg injuries. Access to straw can alleviate some of these negative behavioural problems of hunger but does not increase satiety (Jensen et al., 2015b). The *Council Directive 2008/120/EC* requires that: '*Member States shall ensure that all dry pregnant sows and gilts, in order to satisfy their hunger and given the need to chew, are given a sufficient quantity of bulky or high-fibre food as well as high-energy food*'. Despite this wording, it is estimated that at least 60%−80% of sows are fed a diet with insufficient bulkiness to satisfy their hunger. Feeding sows with *ad libitum* access to fibrous diet can reduce hunger significantly; although weight gain was significantly increased (Jensen et al., 2012). Feeding strategies that adequately reduce hunger through *ad libitum* feeding with bulky high fibre diets while still controlling nutrient intake needs to be developed (reviewed by Bench et al., 2013a), and not least to be implemented on farms. An extensive review on the issue of hunger in pregnant sows is given by D'Eath later in this book.

1.4.3 The farrowing unit

One of the larger welfare challenges of the farrowing unit is that a large majority (estimated to be more than 80%) of farms use farrowing crates with none or limited use of nesting materials. Even if nesting materials are given, they easily get out of reach of the sows and thus are of limited use. When sows are kept under free range conditions, they will seek isolation a few days prior to farrowing and choose a sheltered location where they can build a nest. From approx. 24 hours before farrowing, endogen stimuli motivates the sow for nest building (reviewed by Wischner et al., 2009) and sows will nest build intensively until a few hours before farrowing after which she will lie quietly in the nest while giving birth to the piglets (Jensen, 1986; Stolba and Woodgush, 1989; Jensen et al., 1993).

The ability of crated sows to perform nesting behaviour is limited (Hartsock and Barczewski, 1997; Jarvis et al., 1997, 2001; Damm et al., 2003a). Sows have no control over selection of a nest site, and the nest site in a crate does not fulfil the qualities preferred by sows in terms of isolation (Stolba and Woodgush, 1984; Jensen, 1986), and the possibility to dung outside the nest area (Damm and Pedersen, 2000; Pajor et al., 2000; Andersen and Pedersen, 2011). Crating also prevents thermoregulation, and thus crated sows are likely to be more susceptible to heat stress (Prunier et al., 1997; Quiniou and Noblet, 1999; Muns et al., 2016). In addition to the physical consequences of crating, stress responses have been reported such as increased heart rate (Damm et al., 2003a) and changes in stress hormone secretion (Lawrence et al., 1994; Jarvis et al., 1997, 2006; Oliviero et al., 2008). As sows since 2013 in all EU countries shall be kept in groups during gestation, the long term negative effects of crating (such as reduced muscle and bone strength) will be reduced whereas the more immediate stress response to crating will be increased each time the sows are moved to the farrowing crate (Boyle et al., 2000). The latter may result in prolonged birth (Oliviero et al., 2008, 2010) and increased risk of still birth particularly in young gilts that are confined for the first time (Cronin et al., 1996; Pedersen and Jensen, 2008). The negative effects on both welfare and production parameters highlight the need to change to a sow production without the use of close confinement during any period of the reproductive cycle.

There is good evidence to suggest that loose housing has many advantages that potentially can improve not only the welfare but also the productivity and survival of both sows and piglets. Amongst others, the ability to nest build and the possibility to supply larger amount of nesting materials to the sow has been shown to be beneficial for the farrowing process (Oliviero et al., 2010), for later maternal behaviour (Oliviero et al., 2008; Yun et al., 2014a,b), and for piglet growth (Westin et al., 2014). The ability to perform protective behaviour during lying down also has the potential to prevent neonatal crushing (reviewed by Damm et al., 2005).

The overall mortality rate investigated in countries where loose housing systems are used in larger scales on commercial farms seems to be similar as in the crate system, however with a tendency that penned sows crushed more piglets early, while piglets died later from other causes in the crate system (e.g., Weber et al., 2007; KilBride et al., 2012). In countries with high prolific sows and less experience in the use of farrowing pens, Hales et al. (2014) found in Danish herds an increased mortality in loose-housed compared to crated sows. It is possible that large litter sizes pose a larger challenge in loose housing systems, where sows are able to respond to the extra human interference needed to ensure survival of large litters.

To ensure high survival of neonatal piglets in a farrowing pen for loose-housed sows and to achieve all its potential benefits, pens must be well designed (reviewed by Baxter et al., 2011). They shall meet the needs of sows and piglets during farrowing and lactation and in addition ensure good hygiene and easy access and overview for the caretaker. This includes (reviewed by Pedersen et al., 2013) loose housing throughout the entire periode to reduce stress, a separated nest and dunging area with concrete and slatted floor respectively, provison of extra heat or straw bedding at the nest site to prevent hypothermia of neonatal piglets and provision of a heated creep area after birth, a slurry system that can handle larger amount of nesting materials such as straw, protection walls with escape zones for piglets in the nest area, positioning of feed and water according to knowledge of sow dunging pattern to promote cleanliness of the pen.

To make further progress in the use of loose farrowing systems, the focus needs to be on continuous development of improved pen design, accompanied by documentation of the potential production benefits of the systems, such as piglet growth and survival as well as sow health, longevity and welfare. An extensive review of sow welfare in the farrowing crate and alternatives are given by Baxter et al. in a later chapter of this book (Baxter et al., Chapter 2: Sow welfare in the farrowing crate and alternatives).

Another major concern in the farrowing unit is the ongoing genetic selection for high prolificacy in the sow line, resulting in litter size outnumbering functional teats and accompanied by more dead piglets per litter. As side effects of large litters are prolonged duration of farrowing, reduced birth weight, increased likelihood of pigs suffering from intra-uterine growth retardation, reduced colostrum intake per piglet (Devillers et al., 2007) and lack of teats for all live born piglets (reviewed by Rutherford et al., 2013). In addition, a farrowing crate has insufficient space to accommodate a litter of 14 or more live piglets (reviewed by Pedersen et al., 2013), amongst other access is limited to the sow's udder and for piglets to rest on a comfortable and warm surface away from the sow as required in the *Council Directive 2008/120/EC*. If these negative side effects are not met by adequate management such as birth surveillance, extra care for hypothermic and small unviable piglets, assistance to assure colostrum intake and a functional teat for all piglets, high mortality rates must be expected. In the Danish production an average of 15% of weaned sows are used as nurse sows as described in Section 1.2.3 after having nursed their own litter for 1–3 weeks (Sørensen and Pedersen, 2015). Such procedures affect the welfare of the nurse sows as well as of the litters involved, due to the prolonged crating of the nurse sow (Sorensen et al., 2016). Despite the general concerns for piglet welfare in large litters, concerns about the feasibility of the currently used genotype in less intensive sow farrowing systems can be raised. Longitudinal studies on productivity and welfare of pigs born in large litters are needed both in conventional production systems as well as in alternative systems.

Different mutilations of neonate piglets take place in the farrowing unit such as castration, teeth clipping and/or tail docking. These procedures are known to be associated with the experience of acute pain and possibly also chronic pain. An extensive review of the ability of pigs to feel and experience pain is given by Herskin and Di Giminiani, 2017 elsewhere in this book (Chapter 11: Pain in pigs: Characterisation, mechanisms and indicators).

1.4.4 Weaner unit and rearing unit

The use of early weaning is one of the major welfare problems in the weaner unit. Under semi-natural conditions and in the wild, domestic sows wean their litter gradually starting already from the 2nd week where a sow's motivation to initiate nursing and the frequency of nursing gradually decreases (Jensen and Recen, 1989; Damm et al., 2003b). Depending on the available resources, the weaning process is averagely finalised around the 17th week of lactation (Jensen and Recen, 1989). When piglets are abruptly weaned already at 3−4 weeks of age, they are neither physiologically, immunologically or behaviourally ready to consume larger amount of solid feed (Heo et al., 2013). This results in a dramatic drop in intake of metabolisable energy from the first day of weaning to about 20% of normal intake. The reduction in intake may last for several days and pigs are not fully recovered to the pre-weaning energy (ME) intake level until 2 weeks after. In suckling piglets, solid feed intake gradually increases around the 4th week of life (Boe, 1991), although large individual differences have been reported. The percentage of piglets within a litter with little or none ingestion of solid feed before Day 19 and Day 27 was observed to be 51% and 16%, respectively (Pluske et al., 2007). Pluske et al. also estimated the daily feed intake to average 7−10 g/pig on Day 18, increasing to 40 g/pig on Day 25, and to 100 g/pig on Day 31.

At the time of weaning, piglets are subjected to a large variety of simultaneous stressors. Besides the separation from the sow and the abrupt change in both feed and water source, they experience transportation and handling stress, social stress from regrouping with piglets from other litters, different physical environment and increased exposure to pathogens and dietary and environmental antigens (reviewed by Campbell et al., 2013). Therefore, the weaning process is difficult for piglets to overcome. When the load of stressors becomes too large, it leads not only to poor welfare but also to poor performance, a high risk of weaning diarrhoea and death. The risk of weaning diarrhoea is sufficiently large to urge most farmers to routinely treat all animals with antibiotics through feed or water as a preventive mean to avoid the reduced productivity caused by diarrhoea and other diseases.

A possible way forward to significantly reduce stress at weaning would be to avoid weaning earlier than 4th or 5th week, combined with a procedure where weaned pigs stay in the farrowing pen at least until they have recovered from the nutritional stress of being weaned. Scientific studies to support the positive effects on productivity of such procedures are lacking and need further attention. Proper quantifications may improve the economic evaluation of alternative weaning procedures, taking into account not only the cost of later weaning and of the less intensive use of the farrowing pens, but also the increased gain of higher growth rate, reduced use of antibiotic and reduced feed cost.

Other important welfare risks both for weaners and rearing pigs are the lack of enrichment and lack of space. More than 80% of pigs in the EU are estimated to be housed in fully slatted pens with no biological relevant stimuli. Lack of sufficient biological relevant rooting materials is an important risk factor for the development of tail biting, and may constitute a welfare risk in itself due to lack of fulfilment of the behavioural need for exploration. Pedersen et al. (2014) and Jensen et al. (2015a) found a linear reduction in time spent on abnormal behaviour and increased time spent on straw directed behaviour with increasing amount of straw up to around 300–400 g per pig per day depending on the age of the pigs. Also, stomach ulceration was reduced (Herskin et al., 2016) and growth rate increased (Pedersen et al., 2015) by increasing amounts of straw. An extensive review of tail biting and manipulable materials is given later in this book by Valros and Bracke. At the end of the period in the weaner unit and rearing unit, pigs may also experience stress due to lack of space, both for undisturbed resting and at the feed trough. The increase in stress level may develop into behavioural problems such as tail biting and increased aggression.

Regrouping of both weaners and rearing pigs constitutes a welfare risk in itself. Groups are frequently remixed, due to an aim of keeping the size of pigs within a group as uniform as possible to make the delivery process to slaughter as efficient as possible. Space restriction is particularly problematic at the time of regrouping or at introduction of unacquainted individuals into an established flock. Pigs need space to establish a dominance hierarchy and in absence of sufficient space they cannot show the full extent of subordinate behaviour, and thus, aggression may be provoked and/or sustained for longer periods. Lack of space for resting, particularly occurring as pigs grow older and larger, forces them to lay closer together (Spoolder et al., 2012) and during warm conditions this may result in thermal stress (Hillmann et al., 2004, 2005). To get rid of body heat, pigs change resting sites to a colder area, for example the slatted floor area (Huynh et al., 2004, 2005) and pigs may even wallow in their own urine/faeces; both resulting in pen fouling and poor hygiene (Aarnink et al., 2006). Fouling behaviour may particularly be problematic in partly slatted floor pens at the end of the rearing period and during hot conditions. As long as temperature stays at or below the pigs' thermo-neutral zone, they prefer to rest on the solid part of the pen and therefore defecate on the slatted part. However if temperature increases, pigs are forced to rest further apart from each other and therefore must use the slatted floor for resting, and thus dunging may occur on the solid part too, resulting in poor hygiene.

Finally, gastric ulceration is a major health and welfare problem in intensive pig production resulting in failure to thrive and sudden death. The prevalence has been reported to be around 30% in slaughter pigs and even higher in culled breeding animals (Robertson et al., 2002; de Oliveira et al., 2010; Swaby and Gregory, 2012; Nielsen et al., 2013). Feeding finely grounded pelleted feed is a well-recognised risk factor (e.g., Canibe et al., 2007; Mosseler et al., 2012). In addition, several authors have found that providing between 50 and 1000 g straw per pig per day compared to no or very restricted access to straw, reduced the prevalence of gastric ulceration (Nielsen and Ingvartsen, 2000; Bolhuis et al., 2007; Scott et al., 2007; Di Martino et al., 2013; Herskin et al., 2016; Jensen et al., in prep.), while other failed to find a similar effect (Day et al., 2002).

To reduce or overcome the above mentioned problems, space allowance needs to be reconsidered. The positive effects of increasing space, both in general and at the feeder, for traits of economic importance such as prevalence of diseases, and growth, should be investigated before an increase in space allowance is deemed unsustainable from an economic point of view. Also, there is a need for the EU Directive to be properly implemented on farms both with respect to tail docking and the use of proper manipulable materials. Systems that can handle larger amounts of straw or other organic materials should be considered for new buildings in order to allow for supply of suitable manipulable materials to reduce behaviour and health problems and thereby improve both welfare and productivity of pigs. Focus should therefore be on development of and use of floor type and slurry systems, such as scrapers, for handling of straw or similar materials.

1.5 Conclusions and future development

Despite an increased focus on animal welfare from consumers, policy makers and retailers, there are still major welfare challenges related to each of the different stages in the life cycle of production sows and slaughter pigs. The majority of the problems are related to close confinement or lack of space, lack of enrichment and bulky feed, and breeding for intensive production traits. The welfare problems are often inherently related to the housing and management applied. Consequently, limitations for improving welfare are often set by the specific building, pen design or feeding method, or by the genetics used on the farm. As these factors are not easily changed and rarely without cost implications, suggestions for changes are applied slowly and are often met by resistance from the industry. Suggested ways forward may be deemed unrealistic, and therefore not further investigated, because they do not increase profit at first glance. However, changes that improve welfare may turn out to be profitable in the long run as the increased cost of new housing or increased space can be mitigated by improved health, longevity and productivity of pigs with high welfare. There are on-farm examples where changes have been applied and the end users do recognise the improved welfare as beneficial for their production level, e.g., due to higher growth rate, less diseases or reduced feed costs. Such experiences emphasise a continuous need for research to develop more welfare-friendly production methods and to implement methods on farms to demonstrate in large scale the achieved benefits, in order to encourage more end users to choose new buildings, genetics, etc. that are beneficial for animal welfare.

To make real progress, research and development should focus on the following areas:

1. Development of farrowing housing systems without crates, including possibilities for improved thermal and nutritional aid to low birth weight piglets, and with the possibility to accommodate weaned piglets.
2. Improvement of pen design, feeding systems and floors for dry and gestating sows.
3. Development of feed stuff with bulkiness.
4. Change of breeding goal towards less prolific sows with higher birth weight and survival rate of piglets.
5. Development of slurry systems and floors that function with larger amounts of organic materials.
6. To increase the implementation of new housing and management on farms, focus should also be on documenting a broader spectra of traits including not only production traits but also health of the pigs and longevity of the sows.

References

Aarnink, A.J.A., Schrama, J.W., Heetkamp, M.J.W., Stefanowska, J., Huynh, T.T.T., 2006. Temperature and body weight affect fouling of pig pens. J. Anim. Sci. 84, 2224–2231.

Andersen, H.M.L., Pedersen, L.J., 2011. The effect of feed trough position on choice of defecation area in farrowing pens by loose sows. Appl. Anim. Behav. Sci. 131, 48–52.

Backstrom, L., Algers, B., Nilsson, J., 1994. Effects of sow housing systems on production and health, 13. In International Pig Veterinary Society Congress, Bangkok (Thailand), 26–30 June 1994.

Barnett, J.L., Winfield, C.G., Cronin, G.M., Hemsworth, P.H., Dewar, A.M., 1985. The effect of individual and group housing on behavioural and physiological responses related to the welfare of pregnant pigs. Appl. Anim. Behav. Sci. 14, 149–161.

Baxter, M.R., 1992. The space requirements of housed livestock. In: Phillips, C., Piggins, D. (Eds.), Farm Animals and their Environment, 1992. CAB International, Wallingford, UK, pp. 67–81.

Baxter, E.M., Lawrence, A.B., Edwards, S.A., 2011. Alternative farrowing systems: design criteria for farrowing systems based on the biological needs of sows and piglets. Animal. 5, 580–600.

Baxter, E.M., Andersen, I.L., Edwards, S.A., 2017. Sow welfare in the farrowing crate and alternatives. In: Špinka, M. (Ed.), Advances in Pig Welfare. Woodhead Publishing, Duxford, UK.

Bench, C.J., Rioja-Lang, F.C., Hayne, S.M., Gonyou, H.W., 2013a. Group gestation housing with individual feeding-I: how feeding regime, resource allocation, and genetic factors affect sow welfare. Livest. Sci. 152, 208–217.

Bench, C.J., Rioja-Lang, F.C., Hayne, S.M., Gonyou, H.W., 2013b. Group gestation sow housing with individual feeding-II: how space allowance, group size and composition, and flooring affect sow welfare. Livest. Sci. 152, 218–227.

Boe, K., 1991. The process of weaning in pigs—when the sow decides. Appl. Anim. Behav. Sci. 30, 47–59.

Bolhuis, J.E., van den Brand, H., Staals, S., Gerrits, W.J.J., 2007. Effects of pregelatinized vs. native potato starch on intestinal weight and stomach lesions of pigs housed in barren pens or on straw bedding. Livest. Sci. 109, 108–110.

Boyle, L.A., Leonard, F.C., Lynch, P.B., Brophy, P., 2000. Influence of housing system during gestation on the behaviour and welfare of gilts in farrowing crates. Anim. Sci. 71, 561−570.

Broom, D.M., Algers, B., Pina, T.N., Sanaa, M., Bonde, M., Edwards, S., Hartung, J., de Jong, I., Vilanova, X.M., Martelli, G., 2007. Scientific report on animal health and welfare in fattening pigs in relation to housing and husbandry. EFSA J. 564, 1−100.

Campbell, J.M., Crenshaw, J.D., Polo, J., 2013. The biological stress of early weaned piglets. J. Anim. Sci. Biotechnol. 4, 19.

Canibe, N., Hojberg, O., Badsberg, J.H., Jensen, B.B., 2007. Effect of feeding fermented liquid feed and fermented grain on gastrointestinal ecology and growth performance in piglets. J. Anim. Sci. 85, 2959−2971.

Cronin, G.M., Simpson, G.J., Hemsworth, P.H., 1996. The effects of the gestation and farrowing environments on sow and piglet behaviour and piglet survival and growth in early lactation. Appl. Anim. Behav. Sci. 46, 175−192.

Damm, B.I., Pedersen, L.J., 2000. Eliminative behaviour in preparturient gilts previously kept in pens or stalls. Acta Agric. Scand. Sect. A-Anim. Sci. 50, 316−320.

Damm, B.I., Forkman, B., Pedersen, L.J., 2005. Lying down and rolling behaviour in sows in relation to piglet crushing. Appl. Anim. Behav. Sci. 90, 3−20.

Damm, B.I., Lisborg, L., Vestergaard, K.S., Vanicek, J., 2003a. Nest-building, behavioural disturbances and heart rate in farrowing sows kept in crates and *Schmid pens*. Livest. Prod. Sci. 80, 175−187.

Damm, B.I., Pedersen, L.J., Jessen, L.B., Thamsborg, S.M., Mejer, H., Ersboll, A.K., 2003b. The gradual weaning process in outdoor sows and piglets in relation to nematode infections. Appl. Anim. Behav. Sci. 82, 101−120.

Day, J.E.L., Spoolder, H.A.M., Burfoot, A., Chamberlain, H.L., Edwards, S.A., 2002. The separate and interactive effects of handling and environmental enrichment on the behaviour and welfare of growing pigs. Appl. Anim. Behav. Sci. 75, 177−192.

Devillers, N., Farmer, C., Le Dividich, J., Prunier, A., 2007. Variability of colostrum yield and colostrum intake in pigs. animal. 1 (7), 1033−1041.

de Oliveira, S.J., Bernardi, R.T., Vogt, F.I., Scartezzini, M., Hepp, D., Lunge, V.R., 2010. Gastric ulcers in fattening pigs: isolation of *Arcobacter* spp. from stomachs with different severity of lesions. Acta Sci. Vet. 38, 351−356.

Di Martino, G., Capello, K., Scollo, A., Gottardo, F., Stefani, A.L., Rampin, F., Schiavon, E., Marangon, S., Bonfanti, L., 2013. Continuous straw provision reduces prevalence of oesophago-gastric ulcer in pigs slaughtered at 170 kg (heavy pigs). Res. Vet. Sci. 95, 1271−1273.

Friend, T.H., Taylor, L., Dellmeier, G.R., Knabe, D.A., Smith, L.A., 1988. Effect of confinement methods on phyiology and production of gestating gilts. J. Anim. Sci. 66, 2906−2915.

Hales, J., Moustsen, V.A., Nielsen, M.B.F., Hansen, C.F., 2014. Higher preweaning mortality in free farrowing pens compared with farrowing crates in three commercial pig farms. Animal. 8, 113−120.

Hartsock, T.G., Barczewski, R.A., 1997. Prepartum behavior in swine: effects of pen size. J. Anim. Sci. 75, 2899−2904.

Heo, J.M., Opapeju, F.O., Pluske, J.R., Kim, J.C., Hampson, D.J., Nyachoti, C.M., 2013. Gastrointestinal health and function in weaned pigs: a review of feeding strategies to control post-weaning diarrhoea without using in-feed antimicrobial compounds. J. Anim. Physiol. Anim. Nutr. 97, 207−237.

Herskin, M.S., Jensen, H.E., Jespersen, A., Forkman, B., Jensen, M.B., Canibe, N., Pedersen, L.J., 2016. Impact of the amount of straw provided to pigs kept in intensive production conditions on the occurrence and severity of gastric ulceration at slaughter. Res. Vet. Sci. 104, 200–206.

Herskin, M.S., Di Giminiani, P., 2017. Pain in pigs: characterisation, mechanisms and indicators. In: Špinka, M. (Ed.), Advances in Pig Welfare. Woodhead Publishing, Duxford, UK.

Hillmann, E., Mayer, C., Schrader, L., 2004. Lying behaviour and adrenocortical response as indicators of the thermal tolerance of pigs of different weights. Anim. Welf. 13, 329–335.

Hillmann, E., Mayer, C., Gygax, L., Schrader, L., 2005. Effects of space allowance on behavioural and adrenocortical reactions to elevated temperatures in fattening pigs. Landbauforsch. Voelkenrode. 55, 255–260.

Holmgren, N., Eliasson-Selling, L., Lundeheim, N., 1998. Claw and leg injuries in group housed dry sows. In: Proc 16th IPVS cong, p. 352.

Huynh, T.T.T., Aarnink, A.J.A., Gerrits, W.J.J., Heetkamp, M.J.H., Canh, T.T., Spoolder, H.A.M., Verstegen, M.W.A., Kemp, B., 2005. Thermal behaviour of growing pigs in response to high temperature and humidity. Appl. Anim. Behav. Sci. 91, 1–16.

Huynh, T.T.T., Aarnink, A.J.A., Spoolder, H.A.M., Verstegen, M.W.A., Kemp, B., 2004. Effects of floor cooling during high ambient temperatures on the lying behavior and productivity of growing finishing pigs. Trans. ASAE. 47, 1773–1782.

Jarvis, S., D'Eath, R.B., Robson, S.K., Lawrence, A.B., 2006. The effect of confinement during lactation on the hypothalamic–pituitary–adrenal axis and behaviour of primiparous sows. Physiol. Behav. 87, 345–352.

Jarvis, S., Lawrence, A.B., McLean, K.A., Deans, L.A., Chirnside, J., Calvert, S.K., 1997. The effect of environment on behavioural activity, ACTH, beta-endorphin and cortisol in pre-farrowing gilts. Anim. Sci. 65, 465–472.

Jarvis, S., Van der Vegt, B.J., Lawrence, A.B., McLean, K.A., Deans, L.A., Chirnside, J., Calvert, S.K., 2001. The effect of parity and environmental restriction on behavioural and physiological responses of pre-parturient pigs. Appl. Anim. Behav. Sci. 71, 203–216.

Jensen, M.B., Herskin, M.S., Forkman, B., Pedersen, L.J., 2015a. Effect of increasing amounts of straw on pigs' explorative behaviour. Appl. Anim. Behav. Sci. 171, 58–63.

Jensen, K.H., Jørgensen, L., Haugegaard, S., Herskin, M.S., Jensen, M.B., Pedersen, L.J., Canibe, N., 2017. The dose–response relationship between the amount of straw provided on the floor and gastric ulceration of pars oesophagea in growing pigs. Res. Vet. Sci. 112, 66–74.

Jensen, M.B., Pedersen, L.J., Theil, P.K., Knudsen, K.E.B., 2015b. Hunger in pregnant sows: effects of a fibrous diet and free access to straw. Appl. Anim. Behav. Sci. 171, 81–87.

Jensen, M.B., Pedersen, L.J., Theil, P.K., Yde, C.C., Knudsen, K.E.B., 2012. Feeding motivation and plasma metabolites in pregnant sows fed diets rich in dietary fiber either once or twice daily. J. Anim. Sci. 90, 1910–1919.

Jensen, P., 1986. Observations on the maternal behaviour of free-ranging domostic pigs. Appl. Anim. Behav. Sci. 16, 131–142.

Jensen, P., Recen, B., 1989. When to wean-observations from free-ranging domostic pigs. Appl. Anim. Behav. Sci. 23, 49–60.

Jensen, P., Vestergaard, K., Algers, B., 1993. Nestbuilding in free-rangeing domestic pigs. Appl. Anim. Behav. Sci. 38, 245–255.

KilBride, A.L., Mendl, M., Statham, P., Held, S., Harris, M., Cooper, S., Green, L.E., 2012. A cohort study of preweaning piglet mortality and farrowing accommodation on 112 commercial pig farms in England. Prev. Vet. Med. 104, 281–291.

Lawrence, A.B., Terlouw, E.M.C., 1993. A review on behavioural factors involved in the develoment and continued performance of stereotypic behaviours in pigs. J. Anim. Sci. 71, 2815–2825.

Lawrence, A.B., Petherick, J.C., McLean, K.A., Deans, L.A., Chirnside, J., Vaughan, A., Clutton, E., Terlouw, E.M.C., 1994. The effect of environment on behaviour, plasma cortisol and prolactin in parturient sows. Appl. Anim. Behav. Sci. 39, 313–330.

Marchant, J.N., Broom, D.M., 1996a. Effects of dry sow housing conditions on muscle weight and bone strength. Anim. Sci. 62, 105–113.

Marchant, J.N., Broom, D.M., 1996b. Factors affecting posture-changing in loose-housed and confined gestating sows. Anim. Sci. 63, 477–485.

Marchant, J.N., Rudd, A.R., Broom, D.M., 1997. The effects of housing on heart rate of gestating sows during specific behaviours. Appl. Anim. Behav. Sci. 55, 67–78.

Meunier-Salaun, M.C., Edwards, S.A., Robert, S., 2001. Effect of dietary fibre on the behaviour and health of the restricted fed sow. Anim. Feed Sci. Technol. 90, 53–69.

Mosseler, A., Wintermann, M., Sander, S.J., Kamphues, J., 2012. Effect of diet grinding and pelleting fed either dry or liquid feed on dry matter and pH in the stomach of pigs and the development of gastric ulcers. J. Anim. Sci. 90, 343–345.

Muns, R., Malmkvist, J., Larsen, M.L.V., Sorensen, D., Pedersen, L.J., 2016. High environmental temperature around farrowing induced heat stress in crated sows. J. Anim. Sci. 94, 377–384.

Nielsen, E.K., Ingvartsen, K.L., 2000. Effects of cereal disintegration method, feeding method and straw as bedding on stomach characteristics including ulcers and performance in growing pigs. Acta Agric. Scand. Sect. A: Anim. Sci. 50, 30–38.

Nielsen, E.O., Haugegaard, S., Jørgensen, L., Sørensen, G., 2013. Mavesundhed hos slagtesvin og slagtesøer, Meddelelse. Available online: <http://vsp.lf.dk/Publikationer/Kilder/lu_medd/2013/975.aspx>.

Oliviero, C., Heinonen, A., Valros, A., Halli, O., Peltoniemi, O.A.T., 2008. Effect of the environment on the physiology of the sow during late pregnancy, farrowing and early lactation. Anim. Reprod. Sci. 105, 365–377.

Oliviero, C., Heinonen, M., Valros, A., Peltoniemi, O., 2010. Environmental and sow-related factors affecting the duration of farrowing. Anim. Reprod. Sci. 119, 85–91.

Pajor, E.A., Kramer, D.L., Fraser, D., 2000. Regulation of contact with offspring by domestic sows: temporal patterns and individual variation. Ethology. 106, 37–51.

Pedersen, L.J., 2007. Sexual behaviour in female pigs. Horm. Behav. 52, 64–69.

Pedersen, L.J., Jensen, T., 2008. Effects of late introduction of sows to two farrowing environments on the progress of farrowing and maternal behavior. J. Anim. Sci. 86, 2730–2737.

Pedersen, L.J., Herskin, M.S., Forkman, B., Halekoh, U., Kristensen, K.M., Jensen, M.B., 2014. How much is enough? The amount of straw necessary to satisfy pigs' need to perform exploratory behaviour. Appl. Anim. Behav. Sci. 160, 46–55.

Pedersen, L.J., Herskin, M.S., Forkman, B., Jensen, H.E.J.M.B., Jensen, M.B. (2015). Increasing amounts of straw increase growing pigs' production and health. In: International Conference on Pig Welfare: Improving Pig Welfare–What Are the Ways Forward? (pp. 98-98).

Pedersen, L.J., Malmkvist, J., Andersen, H.M.L., 2013. Housing of sows during farrowing: a review on pen design, welfare and productivity. Livestock Housing: Modern Management to Ensure Optimal Health and Welfare of Farm Animals. Wageningen Academic Publishers, Wageningen, Netherlands, pp. 285–297.

Pluske, J.R., Kim, J.C., Hansen, C.F., Mullan, B.P., Payne, H.G., Hampson, D.J., Callesen, J., Wilson, R.H., 2007. Piglet growth before and after weaning in relation to a qualitative estimate of solid (creep) feed intake during lactation: a pilot study. Arch. Anim. Nutr. 61, 469–480.

Prunier, A., de Braganca, M.M., Le Dividich, J., 1997. Influence of high ambient temperature on performance of reproductive sows. Livest. Prod. Sci. 52, 123–133.

Quiniou, N., Noblet, J., 1999. Influence of high ambient temperatures on performance of multiparous lactating sows. J. Anim. Sci. 77, 2124–2134.

Robertson, I.D., Accioly, J.M., Moore, K.M., Driesen, S.J., Pethick, D.W., Hampson, D.J., 2002. Risk factors for gastric ulcers in Australian pigs at slaughter. Preven. Vet. Med. 53, 293–303.

Rutherford, K.M.D., Baxter, E.M., D'Eath, R.B., Turner, S.P., Arnott, G., Roehe, R., Ask, B., Sandoe, P., Moustsen, V.A., Thorup, F., Edwards, S.A., Berg, P., Lawrence, A.B., 2013. The welfare implications of large litter size in the domestic pig I: biological factors. Anim. Welf. 22, 199–218.

Scott, K., Chennells, D.J., Armstrong, D., Taylor, L., Gill, B.P., Edwards, S.A., 2007. The welfare of finishing pigs under different housing and feeding systems: liquid versus dry feeding in fully-slatted and straw-based housing. Anim. Welf. 16, 53–62.

Sørensen, J.T., Pedersen, L.J., 2015. Omfanget af brugen af ammesøer og mulige tiltag til forbedring af deres velfærd. DCA–Nationalt Center for Jordbrug og Fødevarer, Denmark 6.

Sorensen, J.T., Rousing, T., Kudahl, A.B., Hansted, H.J., Pedersen, L.J., 2016. Do nurse sows and foster litters have impaired animal welfare? Results from a cross-sectional study in sow herds. Animal. 10, 681–686.

Spoolder, H.A.M., Geudeke, M.J., Van der Peet-Schwering, C.M.C., Soede, N.M., 2009. Group housing of sows in early pregnancy: a review of success and risk factors. Livest. Sci. 125, 1–14.

Spoolder, H.A.M., Aarnink, A.A.J., Vermeer, H.M., van Riel, J., Edwards, S.A., 2012. Effect of increasing temperature on space requirements of group housed finishing pigs. Appl. Anim. Behav. Sci. 138, 229–239.

Stolba, A., Woodgush, D.G.M., 1984. The indentification of behavioural key features and their incorporation into housing design for pigs. Ann. Rech. Vet. 15, 287–298.

Stolba, A., Woodgush, D.G.M., 1989. The behaviour of pigs in a semi natural environment. Anim. Prod. 48, 419–425.

Swaby, H., Gregory, N.G., 2012. A note on the frequency of gastric ulcers detected during post-mortem examination at a pig abattoir. Meat Sci. 90, 269–271.

Taylor, L., Friend, T., Smith, L.A., 1988. Effect of housing on in-situ postures of gestating sows. Appl. Anim. Behav. Sci. 19, 265–272.

Terlouw, E.M.C., Wiersma, A., Lawrence, A.B., Macleod, H.A., 1993. Ingestion of food facilitates the performance of stereotypies in sows. Anim. Behav. 46, 939–950.

Theil, P.K., Jorgensen, H., Jakobsen, K., 2004. Energy and protein metabolism in lactating sows fed two levels of dietary fat. Livest. Prod. Sci. 89, 265–276.

Turner, A.I., Hemsworth, P.H., Tilbrook, A.J., 2002. Susceptibility of reproduction in female pigs to impairment by stress and the role of the hypothalamo-pituitary-adrenal axis. Reprod. Fertil. Dev. 14, 377–391.

Verdon, M., Hansen, C.F., Rault, J.L., Jongman, E., Hansen, L.U., Plush, K., Hemsworth, P.H., 2015. Effects of group housing on sow welfare: a review. J. Anim. Sci. 93, 1999–2017.

Weber, R., Keil, N.M., Fehr, M., Horat, R., 2007. Piglet mortality on farms using farrowing systems with or without crates. Anim. Welf. 16, 277–279.

Westin, R., Holmgren, N., Hultgren, J., Algers, B., 2014. Large quantities of straw at farrowing prevents bruising and increases weight gain in piglets. Prev. Vet. Med. 115, 181–190.

Wischner, D., Kemper, N., Krieter, J., 2009. Nest-building behaviour in sows and consequences for pig husbandry. Livest. Sci. 124, 1−8.

Yun, J., Swan, K.M., Farmer, C., Oliviero, C., Peltoniemi, O., Valros, A., 2014a. Prepartum nest-building has an impact on postpartum nursing performance and maternal behaviour in early lactating sows. Appl. Anim. Behav. Sci. 160, 31−37.

Yun, J., Swan, K.M., Vienola, K., Kim, Y.Y., Oliviero, C., Peltoniemi, O.A.T., Valros, A., 2014b. Farrowing environment has an impact on sow metabolic status and piglet colostrum intake in early lactation. Livest. Sci. 163, 120−125.

Sow welfare in the farrowing crate and alternatives

2

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2.1 Introduction

2.1.1 Why is the farrowing period a welfare 'hot spot'?

Within the pig industry, one of the major persistent welfare 'hot-spots' involves the housing of sows in restrictive systems, such as stalls for pregnancy and farrowing crates for parturition and lactation. These confinement systems give rise to a mismatch between biological needs and building design, resulting in a welfare compromise which is a continuing focus for public concern. In some countries, progress has been made towards implementing systems with less confinement. The United Kingdom, Switzerland, Sweden, Norway and Finland have had bans on the use of gestation stalls since the 1990s or even earlier. The EU as a whole implemented a partial ban in 2013 (sows are still permitted to be confined in stalls for up to 4 weeks after insemination). New Zealand and Australian industries voluntarily announced similar partial stall bans for 2015 and 2017, respectively. In Canada any new pregnancy housing built from 2014 must allow for sows to be grouped, with major retailers committing to stall-free supply chains by 2022. The industry in the United States is facing similar pressure from retailers.

Regarding farrowing crates, only Switzerland, Sweden and Norway currently prohibit their use. However, in Europe the 2013 gestation stall ban appears to have galvanised the farrowing crate debate by focussing attention towards any confinement system. This has created industry momentum to trial loose housing resulting in the emergence of several alternative free farrowing systems and pledges from large pig producing nations such as Denmark to have 10% of its breeding herd loose farrowing by 2021 (Danish Agriculture and Food Council, 2016). In the United Kingdom, despite 40% of the breeding herd already farrowing loose in outdoor production systems, the industry stated in their '2020 vision' (BPEX, 2011) that they would continue to focus on finding solutions that allow the sow freedom around farrowing. An interesting debate arose in 2009 in Austria which led to a pledge to phase out farrowing crates by 2033. The debate challenged the legality of the farrowing crate, citing the Federal Animal Welfare Act (AWA) 2005 which states that: 'space and freedom of movement have to be adequate to the animals' physiological and ethological needs. In addition the animals' somatic functions and behaviour must not be disturbed and their ability to adapt must not be

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overstrained. . .[an] animal's freedom of movement must not be constrained in a way which inflicts pain, suffering or harm on the animal' (translation Baumgartner, 2011). Drawing on the plentiful scientific evidence relating to biological needs of the farrowing sow and the impact the farrowing crate has on these needs (see EFSA, 2007; Baxter et al., 2011 for summaries) it was proposed that the farrowing crate was in contravention of the AWA. This case raises an interesting animal welfare debate from a legal perspective and one which could repeat itself at the EU level, where animal welfare legislation is also based not only on the broad principles of animal welfare (i.e., The Five Freedoms) but also on evidence from multidisciplinary animal welfare science (EFSA, 2007).

2.1.2 What are the sow welfare issues in farrowing/lactation?

The farrowing crate was first introduced in the 1960s (Robertson et al., 1966) with the primary aim of reducing live-born piglet mortality by affording greater control over sow posture changes and allowing more efficient managerial inputs to improve piglet survival (e.g., targeted heat source at the birth site) and safety for stockworkers. Crates are generally positioned above slurry pits with slatted or part-slatted flooring, reducing manual labour for removal of dung and ensuring pen cleanliness. As the sow's position is fixed in the crate, the footprint is minimal (typically 1.23 m^2 crate within 3.6 m^2 pen, Baxter et al., 2012). Thus the crate is deemed a highly cost-effective maternity unit. However, whilst it has given benefits for piglet survival (Edwards and Fraser, 1997) it does impose physical restrictions that impact on sow welfare. Lawrence et al. (1994) found elevated plasma cortisol levels in crated sows and hypothesised that this was a consequence of the inability to fully perform natural behaviours such as nest-building (Lawrence et al., 1994; McLean et al., 1998; Jarvis et al., 1998; Jarvis et al., 2004). Satisfactory nest-building behaviour has been linked with positive maternal behaviours during farrowing (Arey et al., 1991; Jensen, 1993; Damm et al., 2003; Pedersen et al., 2003). For example, several authors have proposed a link between high nest-building activity and reduced risk of crushing (Andersen et al., 2005, 2014; Pedersen et al., 2006). Recent work reported higher oxytocin levels in sows afforded greater nest-building opportunities (Yun et al., 2013) with this research demonstrating greater suckling success for piglets as evidenced by greater IgG levels in piglets from loose-housed mothers (Yun et al., 2015). Longer farrowing durations have been reported from sows housed in crates (Vestergaard and Hansen, 1984; Oliviero et al., 2008, 2010; Gu et al., 2011) with associated higher stillborn rates in some (Arey et al., 1992; Oliviero et al., 2008, 2010; Gu et al., 2011) but not all studies (Hales et al., 2014). Higher incidences of savaging of piglets are reported when sows are confined in crates (Lawrence et al., 1994), which is a behaviour rarely seen in sows housed in alternative systems. Aggressive maternal behaviour has a direct effect on mortality via injury and is associated with restlessness (Ahlstrom et al., 2002) and subsequent delays to the ability of the piglets to achieve early suckling, thus affecting mortality indirectly via weakening of the piglets. Thus the device designed to control the influence of the sow in piglet survival (i.e., the crate) can be somewhat counterproductive by increasing the risk factors associated with stillbirth, exacerbating negative maternal behaviours and masking positive ones.

2.2 Ecology of sow reproduction

In order to understand the welfare needs of the sow and her litter, and to design housing and management systems that will optimise both welfare and performance (Baxter et al., 2011), it is necessary to consider the basic biology of the species which dictates many of the behavioural patterns and physiological responses shown by pigs of all kinds. There is information from both the wild relatives of the modern pig (Gundlach, 1968; Fradrich, 1974), and from modern domesticated pigs themselves when placed in natural and seminatural environments (Stolba and Wood-Gush, 1984; Jensen, 1986), which shows that characteristics developed during a long evolutionary history have persisted throughout the millennia of domestication and the decades of intense artificial selection, even when their functional significance has been reduced. The few behavioural differences that are documented between the domestic sow and wild boar are changes in the threshold to express certain behaviours and quantitative differences in their duration and intensity (Gustafsson et al., 1999), but there is no documented addition or removal of behaviours from the behavioural repertoire itself (Price, 1999).

Behavioural ecology is concerned with functional questions about behaviour and how a particular behaviour pattern serves to increase the fitness of an animal in a given environment. Behavioural ecology involves costs and benefits of a behavioural pattern to an individual, and an animal is designed by natural selection to maximise net benefit (Krebs and Kacelnik, 1991). Thus, in any given specific situation, the behaviour of an individual is the outcome of different trade-offs (Andersen et al., 2006a). Optimality modelling can be used to predict which trade-off between costs and benefits will give the maximum net benefit to the individual. However, two separate perspectives on the term optimality need to be considered (Dawkins, 1998). The first is a long-term perspective, where optimal means leaving a maximum number of viable offspring during a lifetime (fitness). The second relates to a short-term optimising of some function in the day-to-day life of the animal, such as the amount of food energy collected within a time period, and which will ultimately be one of many factors making a contribution to long-term fitness. This is true for both wild and domestic species, so what we usually see in equations for fitness contribution is hardly ever lifetime reproductive success in a species but rather the fitness correlates that are represented in the short-term optimum. This is also why domestic species may just as well serve as good model animals in cost/benefit approaches as wild species, for instance in maternal investment models. It is the magnitude of the fitness improvement which will determine the selection pressure on a given behaviour and the likelihood that it will be genetically conserved.

2.2.1 Natural behaviour

For much of the year, the wild sow lives in a small maternal group of related females and their offspring. The group is joined in autumn by a mature boar, and the gestation period of 3 months, 3 weeks and 3 days means that new litters are typically born in the spring when food supply to support lactation will be increasing. Shortly before parturition is due, the pregnant sow increases locomotory activity and starts to roam away from the group (Jensen, 1986). In the 2–3 days before parturition, the sow can travel for many kilometres as she seeks a suitable nest-site which is isolated and partially enclosed, giving protection from the elements and camouflage from potential predators, whilst allowing maintenance of vigilance against approaching threats. This isolation behaviour has important biological functions; it reduces risk of disturbance during the period of farrowing and early piglet establishment, when competition at the udder from older piglets in the group might be fatal, and it reduces risk of disease transfer to the vulnerable newborn piglets. This biological significance of isolation has resulted in the motivation to isolate being retained through domestication, with reports of periparturient sows in pens walking the equivalent of 30 km (Baxter, 1991) and, when given the possibility to choose, selecting farrowing locations that are enclosed or against a solid wall, but never out in the open (Hunt and Petchy, 1987).

Once a nest-site has been selected, the sow will create a concave depression in the ground by digging and rooting behaviours (Graves, 1984). This is important to give structure to the nest which will reduce the risk of piglets accidentally wandering away. The associated behaviours are still observed in domestic sows kept in farrowing crates, although redirected towards bars, floors and drinkers (Lawrence et al., 1994). After hollowing out a nest-site, branches are gathered to border the hollow before collecting and arranging grass and leaves to line the nest (Gundlach, 1968; Fradrich, 1974; Stolba and Wood-Gush, 1984; Jensen, 1986). In natural conditions sows can make very complex nests, with large amounts of material gathered (Zanella and Zanella, 1993). The nest-building behaviour itself involves circling, rooting and lying to arrange the material into a bowl which will both protect and retain the newborn piglets (Wischner et al., 2009). The critical survival value of a good quality nest, and the linkage of this behaviour to the endocrine changes taking place in the sow shortly prior to parturition (Algers and Uvnäs-Moberg, 2007), have ensured that the motivation to show nest-building behaviour has remained unaltered by domestication (Jensen, 2002). In domestic sows, the time spent carrying and depositing substrate correlates with levels of prolactin and progesterone in the blood, which are elevated in late gestation (Castrén et al., 1993a), while nosing and arranging of nesting material correlates negatively with plasma oxytocin (Damm et al., 2002), switching off the behaviour as birth becomes imminent and inactivity facilitates early suckling and reduces crushing risk.

Once farrowing commences, sow behaviour is characterised by prolonged lateral lying and udder exposure. Farrowing in the domestic sow typically lasts 2–3 hours, with piglets expelled at intervals averaging 20 minutes but varying from simultaneous deliveries to gaps of more than an hour. Unlike many other species, sows do not lick the newborn young, but may stand up to inspect their offspring, making nose-to-nose contact before rooting the nest to move piglets out of the way and then resuming lateral lying (Gundlach, 1968; Jensen, 1986). The reactivity of the sow is highest in the early part of parturition, and especially after the first piglet is born, followed by a prolonged nonresponsive phase of several hours before responsiveness returns in conjunction with general activity (Jensen, 1986; Jarvis et al., 1999; Pedersen et al., 2003). This pattern again reflects endocrine changes in the sow (Algers and Unväs-Moberg, 2007). During farrowing, an increase in oxytocin levels promotes uterine contraction for piglet expulsion (Castrén et al., 1993b) and also results in a continuous let-down of colostrum from the teats. Massage of the udder by the suckling piglets feeds back to further stimulate oxytocin release (Algers et al., 1991). As farrowing is completed, and circulating oxytocin levels reduce, colostrum availability changes from continuous to phasic release, with bouts of suckling then taking place at gradually increasing intervals.

In the first days after farrowing, sows spend the majority of time (as much as 90%) lying quietly in the nest, with only brief trips away for foraging and excretion (Jensen, 1986). Nursing bouts are initiated regularly at 20−40 minute intervals. The time spent away from the nest gradually increases, as the demands of lactation stimulate an increased need for feed, and the piglets begin to follow the sow during her foraging bouts. After about 2 weeks the nest is abandoned and the sow and litter rejoin the main group (Jensen and Redbo, 1987). This break with a fixed nest-site allows the sow to increase her foraging range and feed intake as the demands of the growing piglets increase and allows her to start restricting their suckling, encouraging them to forage independently. This is facilitated by the socialisation of piglets with other litters, and they spend increasing amounts of time away from the sow in piglet foraging groups. The sow renews her social relationships with the other adult females and with the dominant boar, and is stimulated to come back into oestrus as the inhibitory effects of suckling on reproductive activity are reduced. The gradually increasing independence between the sow and litter, with progressive reduction in suckling frequency, lead eventually to full weaning of all piglets after 3−4 months (Jensen, 1988; Jensen and Recén, 1989; Newberry and Wood-Gush, 1985). The departure from the nest is followed by a gradual distancing from piglet interactions, which has an important function in preparing the sow for her next litter and hence maximising the lifetime offspring she produces. Once again, these behavioural predispositions have been conserved during domestication and can be seen in modern sows if the housing system allows them to be expressed (Bøe, 1991).

2.2.2 Maternal investment theory

The evolution of parental care will depend on the costs of care to the parent's residual reproductive value as well as on its benefits to the fitness of offspring or other relatives (Williams, 1966; Trivers, 1972). *Maternal care* is a label for any form of maternal behaviour which appears likely to increase the fitness of the offspring, but carries no implications about costs in terms of energy or fitness. In contrast, *maternal investment* refers to the extent to which maternal care of the offspring reduces the mothers residual reproductive value. Each reproductive effort is associated with a cost in terms of reduced future survival rate and fecundity (e.g., Williams, 1966; Gustafsson and Sutherland, 1988), and the domestic sow is a great example of how this biological system works in practice. Furthermore, life history trade-offs are not only between current and future offspring, but also between number and the fitness of each of them (e.g., Lessells, 1991). Sows produce more offspring than normally raised, and pigs fit the pattern of 'facultative siblicide' to a large extent (e.g., Fraser et al., 1995) in that: (1) producing an extra young only implies a small extra investment for the mother, (2) intense sibling competition determines the number of offspring raised, (3) size asymmetry ensures that the most vital young survive. Overproduction of young may increase maternal fitness either by allowing the mother to take advantage of a sudden increase in resource availability (when raising an extra young is suddenly affordable) or availability of 'extras' to replace offspring that die or develop poorly (Forbes and Mock, 1998). The high weighting put on litter size in breeding programmes has led to young gilts giving birth to ever-larger litters, forcing them to invest more in a litter when they are still growing and not fully developed themselves. While resources for reproduction are usually distributed equally over the sow's reproductive life in nature, today's breeding programmes are likely to produce a shift in the maternal investment pattern towards earlier litters, with negative consequences for future reproduction and longevity. However, this is hardly ever studied because, in normal commercial production, nobody has been able to follow the sows for their entire (natural) reproductive lifetime. It is also the young sows that lose most body condition and have the highest risk of developing shoulder ulcers during the lactation period (Ocepek et al., 2016). Through human provisioning of sows and artificial selection for increased reproductive output, we have been able to utilise the 'overproduction' capacity of the sow to increase the number of weaned pigs, but also at a cost of increased sibling rivalry (Andersen et al., 2011; Ocepek et al., 2017). Increased litter size changes the competition climate among siblings at the udder, in that piglets then spend more time in pre- and postmassage of the udder, resulting in shorter nursing intervals, a higher incidence of terminated nursings, an increased proportion of piglets missing milk let-downs, fewer piglets that monopolise more than one teat, and increased piglet mortality due to starvation and maternal crushing (Ocepek et al., 2017). Finally, if the piglets survive until weaning, they have lower, more variable body weights in the larger litters, so that quality of the offspring has then declined.

In natural or extensive housing conditions, sows increase the time they spend away from their litter and reduce their nursing frequency as lactation progresses (Pajor et al., 2002; Pitts et al., 2002; Weary et al., 2002), and this is more marked in animals that have fewer body reserves at parturition, or give birth to larger litters and heavier young (Pitts et al., 2002). By initiating nursing less frequently and terminating suckling bouts more frequently, preventing the postsuckling udder massaging behaviours which may stimulate continued milk synthesis (Algers and Jensen, 1985; Algers et al., 1991), they reduce milk availability, encourage piglets to forage independently and conserve more of their own body reserves in preparation for the next reproductive cycle. When sows are confined in a farrowing crate in close proximity to the piglets, their ability to have behavioural control over this process is reduced, whilst genetic enhancement of leanness and litter size means that their motivation to control suckling is likely to be increased. This conflict explains the increase in physiological stress measures recorded in crated sows as lactation progresses (Cronin et al., 1991). In crates, it is the piglets that are initiating most of the contacts and communication between mother and young, whereas in loose-housing systems the mother can be in charge of interacting with the piglets, leading to a more natural decline in maternal investment over the lactation period from birth until weaning.

2.3 Genetic 'improvement' and its implications

Whilst the preceding section highlights the similarities in basic behavioural patterns between modern domestic sows and their wild relatives, they are very different in many other respects. Domestication can be defined as the process by which a population of animals becomes adapted to humans and to the captive environment by genetic changes occurring over generations and environmentally induced developmental events recurring during each generation (Price, 1984). Background selection pressures favouring behaviours that aid adaptation to human and the human-made environment are combined with specific artificial selection for traits that humans identify as a means to increase production efficiency. Animals that have been selected over many generations for some resource-demanding production trait may allocate resources to this trait at the expense of other fitness-related traits. Thus animals with high production efficiency are better adapted to their home environment, but may react less adaptively to environmental changes and unfamiliar stressors (Andersen et al., 2006a).

Modern sows are the product of many generations of intensive selection for desirable production traits. In early domestication, such selection was carried out by individual farmers in a relatively unstructured way and changes were slow but, as commercial breeding companies assumed greater prominence and scale of operation, the impact of genetic selection has intensified. Initially, selection was focussed on relatively heritable traits affecting meat production such as growth rate and feed efficiency. However, the development of computerised systems for data capture and processing, and statistical approaches to derive genetic information from very large populations of related animals, have made it possible to select for traits with low heritability, such as many of the reproductive and behavioural traits, and accelerated the rate of genetic change which can be achieved in all traits.

2.3.1 Genetic selection criteria and their consequences for sow welfare

The first type of traits to be intensively selected for in pig breeding were those relating to the growth and feed efficiency of the slaughter generation and the quality of the carcass. Whilst the target of this selection was the slaughter pig, the consequences were also seen in the breeding animal. Selection for a reduction in subcutaneous fat thickness in the carcass, a highly heritable trait (h^2 ~0.4), resulted in a dramatic reduction in the level of energy reserves available for lactation in the breeding animal. Edwards (1998) illustrated a reduction of 23%−40% in the subcutaneous fat thickness of typical breeding sows in the United Kingdom over a 10-year period. At the same time, the method adopted to achieve this genetic change had further undesirable side effects. By selecting for animals which produced a lean carcass on an *ad libitum* feeding regime, there was indirect selection for reduced voluntary feed intake (Webb, 1989). As a result, not only did sows enter lactation with reduced energy reserves, but they were also less capable of eating the large quantities of food necessary to sustain the demands of high milk production. A consequence of this was the appearance of the 'thin sow syndrome' on commercial farms (MaClean, 1968), where animals lost excessive amounts of body condition during lactation and failed to recover and rebreed after weaning. Whilst more recent years have seen a slowing of selection pressure for the trait of leannesss, and a focus on better appetite, modern sows have been left in a much more vulnerable state than in the past if nutritional challenges are present. The reduction in subcutaneous fat has also reduced the cushioning properties of the skin making sows more prone to shoulder sores. These occur when sows experience long periods of lateral lying (such as occurs in the post-farrowing period) where there is subsequent sustained pressure on the skin between the bony protuberance over the shoulder joint and a hard floor surface. This pressure occludes blood flow to the area, causing necrosis of the tissue which can increase in severity over time from a superficial inflammation to a deeply eroded ulcer penetrating to the bone (Herskin et al., 2011). Such injuries are more evident in sows losing excessive amounts of weight during lactation (Ritter et al., 1999). Whilst this problem can be influenced by floor type and by sow body condition, it also has a heritable component which may reflect the morphology of the shoulder joint (Lundgren et al., 2011; Lundeheim et al., 2014). This makes it possible to include selection pressure against the problem in the breeding index, and this is now being addressed in some susceptible populations.

The other highly heritable trait to receive early selection was growth rate of the slaughter generation. In selecting for live-weight gain in combination with leanness, the lean tissue growth rate in the young breeding sow increased. This has been associated with two important challenges for welfare. The first is that selection for lean tissue growth rate results in increased mature body size and later age at full maturity of the animal (Whittemore, 1994). In consequence, sows are now much larger than in the past (Edwards et al. 1998; Moustsen et al., 2011). This means that their own nutritional demands for maintenance have been increased, exacerbating the already precarious energy balance in early lactation. The problem is particularly acute for the young breeding gilts, who are now continuing to make substantial body growth throughout their first breeding cycle and facing increasing conflict in allocation of nutritional resources between this function and milk production. Secondly, the increase in body size gives rise to the increasingly conspicuous issue that sows have become too big for many existing farrowing crates, particularly those with no adjustable elements to increase length and width. This has become particularly apparent when examining the dimensions of the modern hyperprolific sow who is over 50% heavier than her equivalent 30 years ago (Moustsen et al., 2011). Physically fitting in the crate and adhering to welfare regulations that each pig should be able to 'stand up, lie down and rest without difficulty' (Welfare of Farmed Animals (England) Regulations, 2007) and welfare codes that 'farrowing accommodation should be so constructed and sufficiently big enough to allow the sow to rise up and lie down again without difficulty' (DEFRA, 2003) is a significant challenge. This increased restriction on movement may be a further exacerbating factor for risk of developing shoulder sores/ulcers and a recent epidemiological survey conducted by Bonde (2008) on 3831 Danish sows from 98 herds found shoulder ulcers in 17% of lactating sows kept in conventional farrowing systems. However prevalence from herds where sows are loose for farrowing show ranges from 10% to 36% in Sweden and Norway, respectively (Herskin et al., 2011), indicating that restrictive housing is not the only risk factor. A recent study documented that a maternal purebred line heavily selected for litter size at birth had higher litter investment, suffered larger losses of body condition and had a higher prevalence of shoulder lesions during lactation than other breeds with less emphasis on litter size. Furthermore, primiparous and multiparous sows at the present time often have similar litter sizes (Ocepek et al., 2016), in contrast to 10 years ago when the primiparous animals had smaller litters (Andersen et al., 2011). Adding the fact that primiparous sows also have a lower total feed consumption during lactation than multiparous sows, the consequence of this is logically that they also suffer greater losses in body condition and develop more shoulder lesions than the multiparous, as previously mentioned.

Historically, the selection for reproductive traits was limited because of their much lower heritability (e.g., $h^2 \sim 0.1$ for litter size). However, new genetic approaches developed and increasingly applied since the 1990s have brought about dramatic changes, with litter size in the EU increasing by 15% over the last 20 years and in some genetic lines by as much as 4 piglets over the same period (Baxter and Edwards, Chapter 3: Piglet mortality and morbidity: inevitable or unacceptable?). Large litter size has a number of associated welfare challenges for both piglets and sows (Rutherford et al., 2013; Baxter et al., 2013). There is a general consensus that larger litters have higher piglet mortality (Blasco et al., 1995; Sorensen et al., 2000). The occurrence of stillbirths is increased, which is in part linked to the longer farrowing durations associated with superprolific breeds. Hales et al. (2014) reported farrowing durations of over 9 hours in superprolific lines (average 7 hours), whereas Peltoniemi and Oliviero (2015) suggested a time limit of 5 hours for a 'successful' farrowing as determined by stillbirth rate and oxytocin concentrations. For live-born piglets, large litter size is a risk factor due to an associated increased proportion of low birth weight piglets being born (Kerr and Cameron, 1995; Roehe, 1999; Sorensen et al., 2000), and the concomitant higher risk of mortality in small piglets. Any farrowing system must function as a protective environment promoting survival, as well as an environment which maximises growth and development. There is pressure on alternative farrowing systems to deliver equal or achieve higher piglet survival figures than reported in crates if they are to be successfully implemented commercially. It is evident that, even in conventional systems, achieving high piglet survival is a challenge when dealing with large litters. In a study comparing piglet mortality in sows in loose pens compared to those confined pre- and post-farrowing, piglet mortality was greater when sows were loose and the authors postulated that the large litter sizes contributed to more piglets being crushed by loose-housed sows compared with sows that were confined (Moustsen et al., 2013). With larger litters, the risk of piglets being crushed increases compared with smaller litters simply because of a greater chance of piglets being close to the sow when she changes position (Weary et al., 1998). In addition, when the number of piglets exceeds functional teat number, large litters require targeted and often intensive human inputs to implement cross-fostering, artificial rearing and establish nurse sows (Baxter et al., 2013). In a crate environment such interventions could be considered easier, with piglet handling unimpeded by the sow. Allowing for such interventions when the sow is loose is an important aspect of alternative system design and is covered further when discussing the biology−management interface (see Section 2.5).

Irrespective of the housing system, raising a large litter places increased demands on the metabolic functions of the sow which can give rise to welfare problems. As sow body size and litter size have increased, so has the milk yield of the sow which is now 50% greater than typical output measured 30 years ago (Edwards, 1998). In addition to all the other changes mentioned previously, this further challenges the ability of the sow to achieve energy balance and maintain body condition, with all the associated detrimental consequences if she fails. The biological impacts of large litter sizes on sow welfare therefore involve issues related to the process of carrying, delivering and raising a large litter (Rutherford et al., 2013) and for nurse sows, drafted in to raise surplus piglets, which must endure a prolonged lactation period and increase the time spent in confinement if crated (Baxter et al., 2013). However there are opportunities for alternative farrowing systems to mitigate some of the negative effects of large litters, particularly addressing some of the issues regarding farrowing duration and sow welfare and the use of nurse sows raising concurrent litters in prolonged confinement (see Section 2.5.3).

2.3.2 Short-term gains versus lifetime implications

It should be apparent from the preceding discussion that, when considering both welfare and productivity of a sow, a single reproductive cycle cannot be viewed in isolation. By selecting animals for traits favouring high productivity in a single litter, such as number of piglets born, or weight of piglets weaned, short-term success may be readily achieved with modern genetic capabilities. However, if taken to extremes, this comes at a cost to the welfare of the animal and ultimately results in reduced efficiency of the system as a whole. This gives rise to the question of whether it is possible for a 'supersow' to also be a robust sow (Ocepek et al., 2016). From an evolutionary point of view (Section 2.2.2), there is a trade-off between current and future litters and between number and fitness of piglets (Lessells, 1991). Ocepek et al. (2016)

demonstrated how a highly selected maternal sow line invested more in their litter in terms of higher litter weight at birth and weaning, but with the consequence of greater loss in body condition and a higher prevalence of shoulder lesions. Moreover, it was only in this genetic line that the development of shoulder lesions could be associated with inadequate feed consumption. Such results, and the genetic correlations now demonstrated between problems such as shoulder ulcers and production traits such as leanness and litter weight (Lundgren et al., 2011; Lundeheim et al., 2014), highlight the importance of improving the balance in future breeding indices between traits giving short-term productivity gain and traits that improve welfare and longevity of the sows. In addition to the welfare costs of the superproductive sow, we have to consider the increased veterinary costs and extra labour demanded from the farmer with the increased litter sizes and their associated negative effects. In countries where the cost of replacing a sow is relatively high, it also pays to keep the sows in production as long as possible. We have shown in recent studies (Ocepek et al., 2016) that it is not possible to prevent the high loss in body condition of young sows by simply providing more feed – they cannot further increase their intake of concentrated feed because of the limitations of their digestive system. Thus, today's selection programme is suboptimal because several costs of the increased productivity have been overlooked, despite the fact that the farmer sees them and experiences them every day on the farm.

2.3.3 Feasibility of selection for robustness and temperament

Given our current advances in the ability to harness genetic approaches, it is reasonable to ask if it might be possible to make more active attempts to select sows for both desirable maternal characteristics which would improve piglet welfare, and for traits which would directly or indirectly improve the robustness and welfare of the sow herself (Knap, 2005). The potential for selecting sows for desirable maternal traits, including behaviour, is discussed in chapters of this book by Baxter and Edwards (Chapter 3: Piglet mortality and morbidity: inevitable or unacceptable?) and by Turner et al., 2017 (Chapter 14: Breeding for pig welfare: opportunities and challenges). When considering selection for sow robustness, approaches include both direct selection for longevity, or selection against characteristics identified as contributing to early removal from the breeding herd such as health disorders including lameness, poor body condition or infertility. The Code of Good Practice for Farm Animal Breeding and Reproduction (EFABAR, 2007), lists 10 traits of welfare and health in pigs: longevity of sow, teat number, maternal ability, vital piglets, survival, stress resistance, absence of congenital defects, leg quality, disease resistance and robustness. Many of the currently selected production traits such as growth and leanness are unfavourably associated with sow longevity (Serenius and Stadler, 2004; Engblom et al., 2009). Gourdine et al. (2010) used simulation modelling to demonstrate how the attribution of much higher weights in the breeding index than normally reported for robustness traits, such as leg strength, rebreeding ability and mothering ability, was necessary to prevent deterioration in these traits against a background of selection for production-related traits. Not all of the 10 welfare and health traits highlighted currently have simple phenotypic measures and heritability estimates are often low (e.g., $h^2 < 0.1$ for longevity traits – Engblom et al., 2009, 2016; 0.2 for leg quality – Kanis et al., 2005). In addition, these traits are often strongly influenced by the production environment. Thus, understanding the biology–building interface is an important aspect of this discussion with possibilities to design systems that might mitigate some of the challenges brought about by intensive breeding strategies.

2.4 Biology–building interface

When designing a suitable alternative to current livestock systems, it is not unreasonable to consider design from the standpoint of the biological needs of the animals involved (Baxter et al. 2011), particularly given that they are the primary users of the system and occupy it for the most amount of time, closely followed by the stockworkers (Baxter, 1983a). However, this concept is rarely applied, with different managerial constraints (e.g., finance, labour, space) often resulting in a compromise with the animals' biological needs. Failure to meet these needs can be counterproductive, as they often contribute to biological fitness which encompasses important economic performance indicators including reproductive potential, number and quality of offspring produced, ability to rear offspring and viability of offspring (Baxter, 1983b). Thus, promoting biological fitness via providing environments that satisfy biological needs should favour high productivity, which is obviously a priority for any pig enterprise. To do this, biologists and ethologists need firstly to obtain sound biological evidence about the physiological and behavioural needs of animals which are sensitive to the physical environment. Secondly, they should translate this information into design data (e.g., dimensions of physical space) for those responsible for designing and building new livestock housing (Baxter, 1983a).

2.4.1 Needs of the sow (and other parties)

To fulfil an animal's physiological needs there are very obvious requirements, including provision of appropriate nutrition and climate to ensure maximum growth, development, health and productivity. However when considering behavioural needs and how to fulfil them there has been much debate. For the purposes of this review, a behavioural need is the need to perform a specific behaviour pattern whatever the environment, and even if the physiological needs which the behaviour serves are fulfilled in other ways (Jensen and Toates, 1993). In addition, in order to demonstrate true need it should be shown that failure to meet this need results in welfare compromise by demonstrating negative consequences when the associated actions cannot be performed satisfactorily. This has been clearly demonstrated with regard to the farrowing crate, as discussed earlier (see Section 2.1.2). The natural behaviour of the sow during the various phases of farrowing (i.e., nest-site seeking, nest-building, parturition, early lactation and late lactation), has been described in Section 2.2 and it is evident that very little variation exists between reports of periparturient behaviour observed in extensively kept domestic sows and their wild counterparts (Stolba and Wood-Gush, 1984; Spinka et al., 2000). The failure of domestication to significantly alter these behavioural patterns indicates that they are functionally important and that the commercial farrowing environment should attempt to accommodate this behavioural repertoire. The discussion of how a system might meet the needs of the sow should not be in isolation from the interests of the other main parties, and reconciling the 'triangle of needs' of the sow, her piglets and the farmer poses different degrees of challenge in different commercial situations. The best solution could be to make the sow do most of the job of taking care of her young herself. It is in the farmer's interest to reduce work load, and it is also in the sow's interest to have as little human disturbance as possible, with any human intervention requiring a positive human–animal relationship that needs to be a part of the everyday routine for everyone that works on the farm. To promote desirable maternal behaviours, basic behavioural needs of the sow have to be met through providing a well- designed pen with nest-building opportunities, and where there is space enough to defecate and urinate away from the nest area. Also, the pen width is extremely important for nursing behaviour and for the sow to be able to orientate in the pen (Cronin et al., 1998). Sow behavioural and physical traits that are directly related to maternal investment and piglet mortality (Ocepek and Andersen, 2017) should be given more weight in the breeding programme, whereas the weighting on litter size should be reduced. A more predictable system of management, consisting of a combination of specific routines, is important around the time of farrowing (Rosvold et al., 2017). As litter sizes continue to increase, especially in the young sows, this puts more demands on the farmer regarding management effort. A skilled farmer would know which sows need assistance and which sows can be left alone. The challenge, however, is that we are not planning and designing houses for those farmers, but for an average stockperson who needs certain rules of thumb for how to work with the sows and which routines that are most important.

2.4.1.1 Design detail to reconcile the triangle of needs

The design detail and then the management of a housing system may be more important for animal welfare than the system itself (Barnett, 2007). For example, when considering nest-building behaviour, from the extensive literature on this behavioural repertoire it would appear that the sow needs space, substrate, isolation and enclosure in order to perform her natural nest-site seeking and then nest-construction behaviour. However, how much space is required to satisfy this need? Jensen (1986) reported that expectant sows travelled 2.5–6.5 km during the prepartum period in search of suitable sites and larger distances have been witnessed under less extensive conditions, with expectant sows in 5 m^2 pens, 'travelling' on average 30 km (Baxter, 1991). Thus the sow needs a certain amount of space in which to perform 'seeking' behaviours, but the complexity of space is likely to be just as important as the quantity, if not more so. If the space is complex and dynamic, thus allowing greater opportunities for the animal to engage in different behaviours, it is likely to reduce the amount of space necessary to accommodate behavioural needs and hence the adverse consequences of confinement (Baxter et al., 2012). However, to achieve good hygienic conditions and less labour regarding cleaning of pens, it is important that there is space enough for urinating and defecating away from the solid resting area. Recent experience indicates that the depth of the slatted floor (i.e., the dunging area) is more important than the depth of the nest area, simply because the sows have become longer (Moustsen et al., 2011). When the sow is standing with her front part in the dunging area and the hind quarters on the solid floor, she will perceive this as standing in the dunging area. This is often why we see urination and defecation in the wrong place. To have visual contact with neighbouring sows and drinkers on the short pen partitions of the dunging area also helps to stimulate the sows to defecate and urinate on the right place. If the sows perceives a quality difference between the two areas of the pen, this will also teach her to use the environment more as intended already from the first day. This can be done by provision of a larger amount of sawdust and/or straw on the solid floor and having water on the slatted floor already before she is let into the pen. Another important design feature is the extent to which the floor in the nest area is perceived as comfortable by the sows and piglets. Using observations of natural behaviour, evidence from a range of studies on animal preference and strength of motivation, as well as biometric equations to determine body space requirements during different activities, Baxter et al. (2011) attempted to quantify design data to allow construction of a suitable farrowing and lactation system to satisfy biological needs. Table 2.1 provides a summary of the main conclusions from this work regarding sow welfare. In undertaking this task it was evident that, despite extensive work to demonstrate needs, further research is required to provide specifics. Preference testing is a hugely valuable aspect of this endeavour, providing a wealth of important information to improve livestock housing and husbandry. However, such choice tests often ask questions in isolation of other factors/attributes that an animal may need in order to judge the preferred options. To fully examine choice and the impact certain environments or elements of an environment have on an animal's welfare requires quite complex dose−response trials, with multilayered options, as well as some quantification of an animal's strength of motivation (i.e., demand measures), complemented by a range of physiological, behavioural or clinical indicators of welfare. Such studies are rare due to their complexity and cost. An additional intricacy is considering the issue of individual variation and how this affects choice. Nicol et al. (2009), when studying laying hens in a longitudinal experiment about environmental preference, found that although birds were relatively consistent in their choices, there was considerable individual variation in the environments chosen. Kruschwitz et al. (2008) also demonstrated in chickens that individual differences in nesting motivation were linked to different preferences (or strength of preference) for environmental features. These authors suggested that any well-designed husbandry system should cater for the minority as well as the majority.

Table 2.1 Summary of relationship between sow welfare requirements (biological needs) and system components of farrowing and lactation accommodation (minimum recommendations are based on extensive literature review in Baxter et al. (2011); where new information has become available recommendations have been updated)

		Component of systems and recommendation				
		Space	**Substrate**	**Walls**	**Flooring**	**General**
Phase of farrowing	Nest-site seeking	Increased activity to find a suitable nest-site separated from feeding and dunging/urination sites to maintain hygiene	Available substrate in vicinity	Sense of isolation and enclosure for protection and to allow vigilance	Suitable to construct a nest Suitable to maintain hygiene	Thermal comfort
		Recommendation = [a]4.9 m^2 with separate differentiated areas to maintain hygiene (will interact with walls and flooring)	Recommendation = 2 kg long-stemmed straw	Recommendation = 3 solid-sided walls creating a cul-de-sac	Recommendation = malleable (e.g., earthen) or solid to accommodate deep substrate	Recommendation = 10°C–22°C[b] is considered the range of thermal comfort for the sow
	Nest-building	Sow needs to be able to gather substrate and then turn around and arrange substrate in to a suitable nest	Suitably complex materials in enough quantity to satisfy carrying and manipulating behaviours during the construction of a suitable nest, provide thermal comfort and provide the sense of a complete nest	Suitable to retain nesting substrate to some degree if nesting substrate not strong enough to create barrier and if flooring unsuitable (i.e., if floor not malleable to create a hollow)	Suitable to construct and retain built nest Suitable to maintain hygiene	Thermal comfort High water intake
		Recommendation = [a]3.17 m^2	Recommendation = 2 kg of long-stemmed straw for carrying and manipulation Recommendation = 10–12 cm[d] depth of straw to provide cushioning and therefore udder comfort. Use of other materials to achieve this (e.g., rubber mats, deep sawdust bedding) requires further investigation	Recommendation = 3 solid-sided walls creating a cul-de-sac	Recommendation = malleable (e.g., earthen) or solid to accommodate deep substrate	Recommendation = 10–22°C is considered the range of thermal comfort for the sow

(*Continued*)

Table 2.1 (Continued)

		Component of systems and recommendation				
		Space	**Substrate**	**Walls**	**Flooring**	**General**
	Parturition	Sows needs to be able to lie laterally and have enough space to deliver piglets	Suitable to maintain thermal and udder comfort and retain piglets in close proximity. There will be an interaction with air temperature and floor properties	Suitably enclosed and dark to simulate burrow and ensure undisturbed parturition	Suitable to provide thermal and physical comfort, including prevention of injury.	Thermal comfort
					Suitable to allow drainage of placental fluids. There will be an interaction with substrate properties	High water intake
		Recommendation = [a]2.79 m^2	Recommendation = Deep bedding 10–12 cm, interactions with floor properties and ambient temperature	Recommendation = 3 solid-sided walls creating a cul-de-sac	Recommendation = High thermal resistance, e.g., rubber matting or deep substrate (interaction with substrate). Temperature differentials in separate areas. Further research needed for recommendation of localised temperature	Recommendation = 10°C–22°C is considered the range of thermal comfort for the sow. Temperature differentials (e.g., zoned heating in nest) to balance sow and piglet needs 2 l/minute[c] to encourage high water intake
					Solid to avoid teat injuries	
	Early lactation/ nest occupation	Sows needs to be able to get up and down unimpeded and be able to turn around to inspect and regroup piglets	Suitable to maintain thermal and udder comfort and retain piglets in close proximity	Suitably enclosed to allow undisturbed suckling behaviour and establishment of mother-offspring bonds with ability to maintain vigilance	Suitable to provide thermal and physical comfort including prevention of injury. There will be an interaction with substrate properties	Thermal comfort
			Substrate for foraging	Suitably supportive to assist posture changes	Suitable to maintain hygiene (there will be an interaction with walls and space)	Moderate feed intake and high water intake to replenish energy from parturition and increase lactational output

		Recommendation = [a]3.17 m^2 Space to defecate/urinate away from nest-site	Recommendation = deep bedding 10–12 cm, interactions with floor properties and ambient temperature	Recommendation = 3 solid-sided walls creating a cul-de-sac	Recommendation = low thermal resistance, e.g., metal. Temperature differentials in separate areas	Recommendation = 10°C–22°C is considered the range of thermal comfort for the sow
		Space to start foraging and feeding away from nest-site Space to allow greater thermal control via posture changes (interaction with flooring and air temperature)		Sloped walls or vertical walls offer support with sloped walls offering additional piglet protection properties	Solid to avoid teat injuries	Interaction with flooring and substrate Water flow rate of at least 2 L/minute to encourage high water intake
	Late lactation	Increased activity to allow departure away from nest-site and gradual separation from piglets and controlled nursing	Substrate for foraging	Suitable to allow social contact (visual and physical) with nonlitter pigs	Suitable to provide thermal and physical comfort including prevention of injury. There will be an interaction with substrate properties	Thermal comfort High feed and water intake to maintain lactational output and body condition
		Space to ensure thermal comfort via posture changes (interaction with flooring and air temperature) Space to allow social contact with conspecifics		Suitably supportive to assist posture changes	Suitable to maintain hygiene (there will be an interaction with walls and space)	
		Recommendation = separate area from nest-site, separate space inaccessible to piglets with 'clever design' to accommodate different activities	Recommendation = research needed	Recommendation = vertical barred area within pen divide	Recommendation = low thermal resistance, e.g., metal. Temperature differentials in separate areas	Recommendation = 10°C–22°C[b] is considered the range of thermal comfort for the sow
				Sloped walls or vertical walls offer support with sloped walls offering additional piglet protection properties	Slatted area for dunging/urination	Interaction with flooring and substrate

[a]Space dimensions determined by using biometric equations and principles for animals undertaking different activities (Baxter and Schwaller, 1983; Petherick, 1983).
[b]Temperature recommendations based on Black et al. (1993).
[c]Water flow recommendations based on work by Gonyou (1996) with 2 L/minute required for button press or bite drinkers.
[d]Bedding depth recommendations based on observations by Baxter et al. (2009).

The problem with such ambition regarding farrowing and lactation systems is that certain choices may affect the welfare of other stakeholders. For example, in a loose system the sow can choose to farrow in any available location. If this choice is in an area considered risky for the piglets (e.g., in a dunging passage, or outside a farrowing hut) it will negatively affect their welfare and increase the risk of mortality. By providing stimuli to simulate an attractive nest-site, the aim is to encourage the sow to make the best choice for her and her piglets. Baxter et al. (2015) achieved this by providing a nest-site with clear distinction from dunging and feeding areas (a preference for sows, Wiepkema, 1986; Damm and Pedersen, 2000), having enclosure with solid walls, sufficient substrate with which to satisfy nest-building behaviour and suitable flooring to maintain the nest. Andersen (2016) used similar stimuli to create a defined area and then used underfloor heating in the nest-site to create different temperature profiles for the sow and the piglets, reflective of their highly dichotomised thermal needs, at the same time creating a nest area where the sow can be in direct contact with the piglets all the time and not separated from them by use of a creep area. We should favour a selection environment where the sow's maternal behaviour is stimulated and where it is easy to distinguish between good and bad mothers so that the farmer can cull the ones who are not adapting to the system. Overall, it is a good sign when young sows show immediate preferences for a pen by performing well and showing calm and positive behaviours as opposed to restless and negative behaviours. In the long run, this will result in a population of self-sufficient and well adapted sows. By creating systems that understand and work with the biological needs of the animals involved, rather than battling against them, it is possible to achieve outcomes that enhance welfare and promote good performance.

2.4.2 What systems are available?

A wide variety of alternative farrowing systems have been developed in research or in practice that vary in how well they reconcile the needs of various stakeholders (Baxter et al., 2012). Although many different systems exist, for the purposes of this review, they can be grouped within broader categories based on common features.

Temporary crates: The majority of these systems essentially involve a widening of the existing farrowing crate to either allow the sow to be able to turn around throughout farrowing and lactation (e.g., Ellipsoid – Lou and Hurnik, 1994) or restrain the sow during farrowing before opening the crate up approximately 5–7 days post-farrowing (e.g., Open crate – Weber, 2000; Combi-flex – Chidgey et al., 2016). Such systems have a starting point of utilising the existing footprint of a conventional farrowing crate space (approximately 4.3 m^2), building on fully slatted floors and retaining the ability to restrain the sow if necessary (Fig. 2.1A,B gives examples). The exception within this category is the SWAP pen (Fig. 2.1C – Sow Welfare and Piglet Protection – Hales et al., 2015) which aimed to 'start with a pen' that was larger than the crate space (6 m^2) and that could meet some of the design criteria proposed to satisfy biological needs (Baxter et al., 2011) and then

Figure 2.1 Temporary crating systems for farrowing and lactation in closed (top line) and open (bottom line) positions. (A) 360° Farrower, United Kingdom and (B) Combi-flex, DK are typical temporary crate options, built on the same spatial footprint as the conventional farrowing crate where sows are often confined in the crate on entry to the farrowing house until approximately 5–7 days postpartum. (C) The SWAP pen, DK, is based on a free farrowing pen design, built on a larger footprint with the intention that-sows are housed loose for farrowing and then temporarily crated post-farrowing for management of piglets.
Source: Pictures from www.freefarrowing.org.

incorporate a confinement option. This pen was developed in Denmark where the advent of superprolific breeding programmes has resulted in the production of consistently large litter sizes, with average litter size reported as 16.6 (Rutherford et al., 2013) compared with an EU average of 13.2 for the same period (AHDB Pork, 2013). Such large litters often need targeted management to deal with surplus piglets and it could be suggested that temporary confinement postpartum assists with this process.

Simple pens: These systems include a range of modified designs in which the crate is absent. The hillside or sloped pens (e.g., hillside pens – Collins et al., 1987) attempted to occupy a similar footprint to that of the conventional farrowing crate, with fully slatted floors, to facilitate good pen hygiene, which were profiled with the intention of directing piglets towards the creep area and away from the sow lying area. Evolutions from this included the addition of extra piglet protection

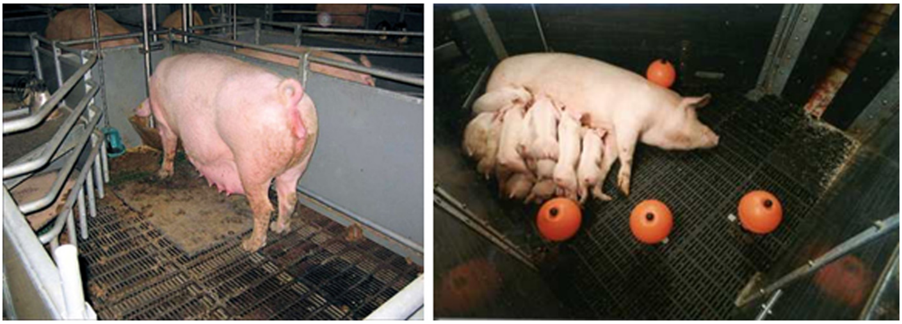

Figure 2.2 Simple pen designs built on the same footprint as the farrowing crate but no restraint options. Additional piglet protection features were added to the centre of the pen to protect piglets from sow posture changes.
Source: Pictures from www.freefarrowing.org and BPEX (2004).

features to provide protection for the piglets from sow posture changes by replacing rails with mushroom-shaped protrusions placed throughout the pen (BPEX, 2004). Fairly simple pen designs include larger, solid-floored, straw-based systems (reviewed in Phillips and Fraser, 1993). Fig. 2.2 shows examples of simple pens.

Designed pens: The most elaborate individual pen systems are so called 'designed pens,' which differ from simple pens because they have defined regions including separate dunging and lying areas, as well as additional pen 'furniture' such as rails or sloped walls to assist sow posture changes and protect piglets (e.g., Schmid pen – Schmid, 1994; FATs – Weber, 2000 (Fig. 2.3A); Werribee farrowing pen – Cronin et al., 2000; Danish Free Farrower – Moustsen et al. 2013 (Fig. 2.3B); Welcon (Fig. 2.3C); SowComfort Farrowing Pen – Andersen, 2016 (Fig. 2.3D) and PigSAFE (Edwards et al. 2012; Baxter et al., 2015 – Fig. 2.3E)). The footprint for such pens varies depending on 'brand', from 5 to 8.5 m^2, with dimensions based on biometric calculations of the sow and piglets (based on extrapolating equations from Baxter and Schwaller, 1983 and Petherick, 1983) in relation to specific functions (e.g., space needed to turn around, suckle, group piglets, etc.).

Group systems: These systems allow sows and litters to mix before weaning. The majority are based on multisuckling accommodation; both sows and piglets are afforded a much greater amount of space and systems are often deep-straw bedded. For farrowing, sows are initially individually housed in pens (or crates, e.g., Bohnenkamp et al., 2013) but are integrated with their litter into groups in larger multisuckling pens between 10 and 21 days postfarrowing (e.g., Ljungstrøm – Goetz and Troxler, 1995; Bäckström et al., 1994; Marchant et al., 2000; McGlone, 2006, e.g., Fig. 2.4A). Alternatively, sows are already grouped prior to farrowing and have free access to individual nest-boxes for farrowing, which may or may not be removed 7–10 days postfarrowing (Thorstensson – Mattsson, 1996; Marchant et al., 2001; Free access systems: e.g., Get away pens – Bøe, 1993; Freedom farrowing – Baxter, 1991; Crated then grouped – Marchant et al., 2000; van Nieuwamerongen et al., 2015 – Fig. 2.4B). The Family Pen system was derived

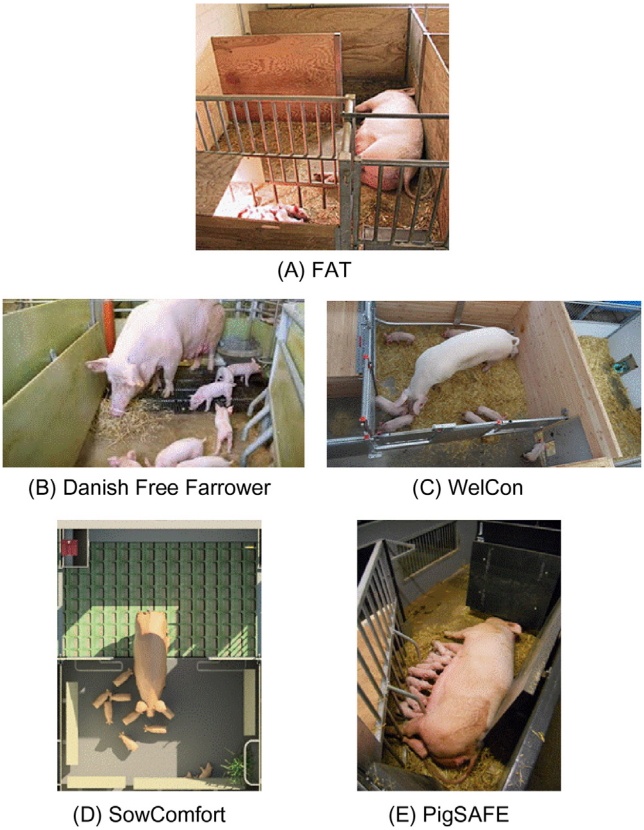

Figure 2.3 Designed pens with defined areas to fulfil different functions. (A) FAT, CH; (B) Danish Free Farrower, DK; (C) WelCon, AUT; (D) SowComfort, NO; (E) PigSAFE, United Kingdom.
Source: Pictures from www.freearrowing.org.

from observing sows and piglets under seminatural conditions and attempting to fulfil the observed needs in a more complex group design (Stolba and Wood-Gush, 1984; Kerr et al., 1988). van Nieuwamerongen et al. (2014) provide a comprehensive review specific to group systems.

Outdoor systems: These are systems with low capital investment and running costs (Guy et al., 2012), where sows and their piglets are housed individually, outdoors in farrowing arks or huts, with access to individual or group paddocks. There are different ark and hut designs available (Fig. 2.5A) and described in detail elsewhere (e.g., Honeyman et al., 1998; Baxter et al., 2009). Outdoor runs with kennels or Solari pens (e.g., Grissom et al., 1990; BPEX, 2004) are systems which attempt to offer more managerial control than full outdoor systems by providing a separate heated creep area inaccessible to the sow, as well as operating on a smaller footprint with kennels often aligned next to each other (Fig. 2.5B). Systems with

Figure 2.4 Group-farrowing and lactation systems featuring system (A) multisuckle where sows farrow individually and then move to simple multisuckle pens after approximately 10 days postpartum or (B) and (C) where sows are grouped before farrowing but can retreat into individual nest-boxes for farrowing.
Source: Pictures from www.freefarrowing.org.

outdoor space are a requirement of some labelling schemes which have higher welfare standards than the minimum required by national legislation (e.g., RSPCA Assured/Freedom Food, Soil Association Organic).

2.4.3 How well do they meet the needs?

2.4.3.1 Evaluating the welfare attributes of systems

An assessment of how well alternative systems satisfy design criteria that best meet the animals' biological needs has already been attempted by the authors (Baxter et al., 2012). They developed a welfare design index by asking a series of questions based on whether components of that system met biological needs. The welfare rationale of the questions was based on Baxter et al. (2011) in their review of biological needs and is summarised in Table 2.1. The questions concerned different attributes of the system including both physical (e.g., quantity of space and substrate, amount of enclosure, etc.) as well as biological (e.g., facilitation of hygiene and health care). Each question asked of a system represented a 'welfare point' if answered positively and a final 'welfare index score' came from dividing the number of positively answered questions by the number answered in the negative.

Figure 2.5 (A) Typical outdoor commercial farrowing huts and arks and (B) Kennel and Run or 'Solari' system.
Source: Pictures supplied by www.freefarrowing.org.

Table 2.2 replicates these questions. As questions were asked based on both sow and piglet welfare, the score then required weighting to ensure that each individual piglet's welfare was considered of equal importance to that of the sow. Thus any question directly relating to piglet welfare was multiplied by the average live-born litter size at that time in the United Kingdom of 11; this score could obviously adjust according to litter size. The methodology was particularly cautious, choosing not to double weight any design criteria that would promote good maternal behaviour and therefore indirectly influence piglet survival (e.g., plentiful nest-building substrate, enclosure to achieve optimum farrowing location). However, given the potential piglet survival benefits associated with sow behaviours that are sensitive to the physical environment, it should be a future endeavour to investigate how best to weight these indirect factors.

Systems were grouped together based on common attributes as described above (see Section 2.4.2). Using this methodology, the derived welfare index score for the

Table 2.2 List of questions that could be 'asked' of a farrowing and lactation system to determine its welfare attributes

Phase	Question of system
Nest-building	Can the sow isolate herself?
	Is there possibility for visual contact with other sows?
	Is there 1 wall?
	Are there 2 walls?
	Are there 3 walls?
	Are there 4 walls?
	Is there a roof?
	Is there enough space for the sow to turn around (floor space = 2.44 m^2 and planar space 3.17 m^2)?
	Is there space for increased activity? (At least 4.9 m^2)
	Is the space defined into separate areas for different activities (e.g., feeding and dunging)?
	Is the space above 5 m^2 to allow at least two defined areas?
	Is the space above 10 m^2 to allow at least three defined areas?
	Is any substrate given?
	Is substrate above 2 kg? (the minimum recommended for nesting)
	Is substrate enough to cover the floor of the nest area provided? (0.60 kg covers 1 m^2 at a 5 cm depth)
	Is substrate deep bedded? (1.20 kg covers 1 m^2 at a 10 cm depth)
	Is substrate complex?
	Is flooring suitable for nesting material?
	Is flooring pliable for rooting?
	Is ambient temperature suitable for the sow − not above 20°C for heat stress?
Parturition	Is the space defined with a separate nest area?
	Is the sow loose for farrowing?
	Is there enough space to turn around for piglet inspection and grouping?
	Is the nest-site undisturbed (as determined by degree of enclosure)?
	Is substrate enough to cover the floor of the nest area provided? (0.60 kg covers 1 m^2 at a 5 cm depth)
	Is the floor profiled to assist teat seeking?
	Is there protection for the piglets (e.g., sloped walls, farrowing rails, 'furniture')?
	Are there sloped or vertical walls to aid sow posture changes?
	Is the temperature above uncontrolled/ambient temperature?
	Is the temperature above 22°C to minimise piglet hypothermia?
	Is there a local heat source for the piglets?
	Is there protective substrate (e.g., deep bedding)?
	Is the flooring suitable to reduce conductive heat loss (i.e., solid insulated or deep bedding)?
	Is there opportunity for safe handling by the staff (i.e., sow lock-in area)?

(*Continued*)

Table 2.2 (Continued)

Phase	Question of system
Lactation	Is the space defined? Is the sow loose? Does the flooring prevent sow slip injury? Does the flooring prevent piglet injury (e.g., slat void below 10 mm)? Does the floor protect piglet legs? (e.g., deep bedding, suitable plastic coating) Does the floor prevent sow teat injury (i.e., solid)? Is the flooring hygienic (i.e., sloped or slatted/part-slatted)? Is there a getaway area for the sow? Is there continuous sow contact for piglets? Can the sow physically contact other sows? Is there visual contact with other sows? Is there the opportunity for full integration with sows? Is there an opportunity for piglets to integrate with other litters? Does the system limit disease transfer? Is there a separate area for piglet protection, inaccessible to the sow (e.g., a creep)? Is there protection for the piglets (e.g., sloped walls, farrowing rails, 'furniture')? Are there sloped or vertical walls to aid sow posture changes? Is the ambient temperature below 22°C? Is there a local heat source above 22°C? Is there enrichment for piglets via adequate social space (e.g., above 5 m^2)? Is there enrichment for piglets via provision of substrate? Is there opportunity for safe handling by the staff?

Questions based on the biological needs of the sows and piglets during the different phases of farrowing (nest-building, farrowing and lactation Baxter et al., 2011).
Source: Table replicated from Baxter et al. (2011).

conventional farrowing crate system was 0.95, with different temporary crating systems only scoring fractionally higher between 1.19 and 1.37. Commercial outdoor systems scored 1.10 and group-farrowing or multisuckling systems scored between 1.19 and 2.20 (e.g., Ljungstrøm − Thorstensson). The designed pens scored the highest out of the individual pen systems at 1.74. To tackle the issue of piglet mortality (arguably a welfare criterion) the welfare design index asked questions relating to design features that may prevent piglet death. For example, crushing is the most common ultimate event preceding live-born death, although hypothermia and starvation are often underlying factors resulting in the neonate being more susceptible (Edwards, 2002), thus questions relating to piglet microclimate and protection from sow posture changes are prominent. However, even if, on paper, systems should promote high piglet survival, actual performance figures are required to make an accurate assessment of system performance.

2.4.3.2 Evaluating system production performance

Performance of alternative farrowing systems has been reviewed in detail by a number of authors (e.g., Edwards and Fraser, 1997; Baxter et al., 2012) and what is apparent in the literature is that different systems show a great deal of variability in their performance. Some comparative studies of conventional crates and different types of individual pen report no significant difference in piglet mortality (e.g., Pens vs Crates: Cronin et al., 2000; Jarvis et al., 2004; Weber et al., 2007; Pedersen et al., 2011a,b; Melisova et al., 2014; Edwards et al., 2012). Other studies report higher mortality in pens compared to crates (e.g., Blackshaw et al., 1994; Bradshaw and Broom, 1999; Moustsen et al., 2013; Hales et al., 2014). There seems to be a general consensus in the literature that multisuckle (group-farrowing) systems result in higher piglet mortality than conventional systems (Bates et al., 2003; Marchant et al., 2000) and higher mortality than that observed from loose but individual pen systems (Baxter et al., 2012). What is consistently reported from studies using these multisuckle systems is that there is a great deal of variability amongst animals (see van Nieuwamerongen et al., 2014 for a review). Thus, despite high welfare scores, group systems require further refinements to achieve acceptable and consistent performance. Few studies exist that have compared performance of alternative systems against conventional systems at a commercial scale (i.e., with large enough sample sizes to deliver meaningful data). Commercial data are available from countries where the crate is banned; data from 99 farms in Switzerland where sows were kept loose for farrowing showed an average live-born mortality rate of 11.8% (Weber et al., 2009). Earlier studies by these authors (Weber et al., 2007) demonstrated from an extensive data set (655 farms comprising 63,661 litters) that piglet losses in farms with loose farrowing pens were no greater than in farms with farrowing crates (total mortality (stillbirths + live-born deaths): loose = 17.2% from 18,824 litters and crates = 17.9% from 44,837 litters). In the United Kingdom, 40% of the breeding herd are farrowed under outdoor commercial conditions (Guy et al., 2012) and comparing key performance indicators between commercial indoor and outdoor herds suggests that outdoor systems can deliver consistently favourable production figures; average data collected from industry databases over the last 14 years shows total mortality as 16.6% outdoors versus 19.3% indoors, and live-born mortality as 11.5% outdoors versus 12.1% indoors (Meat and Livestock Commission/BPEX Pig Yearbooks 2001−2015). In Norway, although no comparative data are available, data from 39 herds with loose-housed sows in individual pens showed an average live-born mortality figure of 15.2%, ranging from 5% to 24% (Andersen et al., 2007). Similar ranges (8%−18%) are reported by the authors tracking commercial uptake of designed pens in the United Kingdom. Work in Denmark (Moustsen et al., 2013; Hales et al., 2014) has stated that piglet mortality is higher in loose systems, specifically in the first 24 hours before litters are equalized; Hales et al. (2014) reported 13.7% versus 11.8% total mortality within this period and Moustsen et al. (2013) reported similar prefostering problems. Large litter sizes, sow parity and farm variability significantly influence the results (Hales et al., 2014). These authors highlight that management and pen design are having important effects on performance.

Piglet survival relies on the coordinated expression of the sow, her piglets and the environment. Thus many aspects can influence piglet survival (Baxter and Edwards, Chapter 3: Piglet mortality and morbidity: inevitable or unacceptable?) and large litter size is one of the major risk factors. To achieve consistent performance the biology–management interface must be addressed.

2.5 Biology–management interface

Management to promote high levels of sow and piglet welfare is not confined to just the farrowing and lactation period. Preparing for farrowing and lactation begins as early as selection of replacement breeding stock and continues during the 'dry' phases of the gilt/sow's life cycle (Pedersen, Chapter 1: Overview of commercial pig production systems and their main welfare challenges). This includes development of a positive human–animal relationship, which should be fostered as early as possible, to prevent fearfulness which can impact not only on the welfare of the sow but also on performance traits (Hemsworth et al., 1995, 1999).

2.5.1 Human–animal interaction

Regardless of farrowing system, people remain the most important contributor to animal welfare outcomes (Tallet et al., Chapter 13: Pig-human interactions: creating a positive perception of humans to ensure pig welfare). The sow will perceive interactions with humans as either aversive, positive or neutral depending on the quality of the interaction (Waiblinger et al., 2006). Perception will be based on interactions experienced throughout their lives (Janczak et al., 2003) and influenced by their temperament. Not only can staff interactions affect sow welfare directly, but they can also impact on piglet outcomes, both indirectly through perinatal programming or more directly in relation to reproductive performance. For example, fear of humans in sows has been reported by Hemsworth et al. (1999) to be positively associated with the percentage of stillborn piglets in a litter. Lensink et al. (2009) reported a similar association with crushing of piglets within the first 24 hours postpartum. Sows experience a number of handling procedures throughout their lives; they undergo routine vaccinations, movement from building-to-building or pen-to-pen, oestrus detection and subsequent artificial insemination and potential farrowing interventions to assist delivery (Prunier and Tallet, 2015). The capacity for these encounters to be aversive (i.e., painful or fear-inducing) is great. Whilst it is recognised that some painful procedures are necessary, they can be exacerbated if the handling is poor or accompanied by fear-inducing stimuli such as loudness and/or roughness. Different coping styles will also influence the sow's response to handling and can impact on behaviours relevant to the farrowing environment. A relationship between a shy or anxious behavioural profile and later impairments of maternal behaviour was shown in a study by Marchant-Forde (2002), who classified gilts on a behavioural 'shy-bold' continuum on the basis of their response in a human-approach test conducted during gestation. Gilts at the shy end of the spectrum were more likely to savage their offspring. Increased fearfulness may be a significant risk factor for piglet-directed aggression, with piglet-directed aggression being proposed as a neophobic reaction towards the newborn piglets (English et al., 1977). It could be suggested that the consequences of piglet-directed aggression could be much more severe in a loose farrowing environment. However, Ison et al. (2015) reported that piglet-directed aggression subsided quicker in gilts in loose-housed farrowing accommodation compared with crates, postulating that the loose housing gave the gilts an opportunity to adjust quicker and develop appropriate mother–young bonds. More general detriments to sow maternal behaviour as a consequence of maternal anxiety were reported by Janczak et al. (2003) who found associations between behavioural measures of fear and anxiety at around 2 months of age and later quality of maternal care as reflected by piglet mortality. Positive handling of pigs, even from an early age, has benefits including reducing the fear response (Hemsworth and Barnett, 1992; Muns et al., 2015). Both English et al. (1999) and Andersen et al. (2006b) found that even brief positive interactions (e.g., soft tactile, visual and auditory contacts) performed daily increased approach behaviours and confidence scores in sows, with both authors finding positive outcomes for farrowing kinetics. The scope to foster positive human–animal interactions has become increasingly rare under modern farming conditions, where many potential positive encounters (e.g., feeding) are automated and the ratio of staff to pigs is low. Over one reproductive cycle, Prunier and Tallet (2015) estimated that staff will spend just 4 hours of their time per sow (based on work by Roguet et al., 2011) and, as discussed already, many of these interactions will involve stimuli that are potentially aversive including handling piglets. Consequently, positive human–animal interactions should be created within the limited time stockworkers spend with sows. This may be particularly beneficial in a loose-housing situation when farrowing and lactation husbandry will involve a greater interaction between the sow, the staff and the environment.

2.5.2 Pharmalogical intervention around farrowing and supervision

There are a number of pharmalogical aids that can be used around the time of farrowing, including administration of prostaglandins in order to synchronise the onset of farrowing and allow targeted supervision, use of oxytocin to assist with farrowing progression, initiate milk ejection or help treat udder conditions such as MMA (mastitis–metritis–agalactia), as well as use of sedatives for piglet-directed aggression and antiinflammatories to treat pain and inflammation (Mainau and Manteca 2011; Kirkden et al., 2013; Ison et al., 2016). Whilst there are benefits to such aids, the misuse of drugs can incur significant welfare detriments for both the sows and piglets, the latter of which have been discussed elsewhere (Baxter and Edwards, Chapter 3: Piglet mortality and morbidity: inevitable or unacceptable?). There are isolated reports that, following prostaglandin administration, sows show transient signs (<1 hour) of abdominal discomfort such as arching of the back (Robertson et al., 1978) or occasional vomiting (Downey et al., 1976). Issues associated with oxytocin administration are more commonly reported and have been discussed in detail by Kirkden et al. (2013). Oxytocin induces contraction of uterine deep muscles, creating a rhythmic and intermittent contracting of the uterus. It has unpredictable effects on farrowing progression, especially when administered before parturition (sometimes in conjunction with prostaglandin administration), with some authors reporting greater increase in farrowing length (Mota-Rojas et al., 2006) and need for greater assistance for both sows and piglets following administration (Welp et al., 1984; Chantaraprateep et al., 1986; Dial et al., 1987), as well as a greater number of intrapartum stillbirths (Mota-Rojas et al., 2002). Reports of dystocia following prepartum administration are likely a result of the cervix not being fully dilated (Gilbert, 1999). Sows with oxytocin administered when the cervix is fully dilated will experience quicker delivery of piglets but if the cervix is partially or fully closed sows will experience dystocia, which is likely to be painful and might cause release of adrenaline, inhibiting further uterine contractions (Cassar et al., 2005). All of this is likely to contribute to maternal fatigue. There is an interaction with farrowing environment; Mota-Rojas et al. (2002) and Alonso-Spilsbury et al. (2004) conducted oxytocin trials in sows farrowing in crated and penned accommodation, respectively. Sows were treated with different doses of oxytocin or not treated at all (control). Intrapartum stillbirths in both control and treated sows were halved when sows were farrowed in pens. However in these studies dystocia was reported in the penned, but not crated sows. The authors proposed that saturation of oxytocin receptors could be occurring, in part due to naturally occurring oxytocin levels being higher in sows loose-housed and given the ability to perform nest-building behaviour (Lawrence et al., 1992; Yun et al., 2013). Several authors have proposed that oxytocin should not be used for the induction of farrowing, but reserved for treating cases of dystocia once farrowing has begun (Kirkwood et al., 1996; Gilbert, 1999). If drugs are to be used in conjunction with induction, carbetocin, as a longer-acting synthetic analogue of oxytocin, appears to have fewer detrimental effects for both piglets and sows (Kirkden et al., 2013). However, any routine use of drugs should be avoided, not least because such administration increases the number of negative interactions between the sow and the stockworkers. This could be counterproductive to farrowing supervision, particularly in a loose-housed environment. For instance, high levels of fear in response to human presence may cause greater reactivity in sows at a time when inactivity is key for piglet survival. Even if the human–animal relationship is positive on-farm, the benefit of supervision in terms of ability to intervene to help individual piglets may also be reduced in noncrate farrowing systems, where safe access to piglets by human stockhandlers is greatly reduced. This is a critical design factor, especially in the context of managing piglets from superprolific sows.

2.5.3 Cross-fostering and nurse sows

Management interventions to promote piglet survival have been detailed elsewhere (Baxter and Edwards, this volume). This section will focus on the sow welfare issues relating to these practices and their interaction with the farrowing environment. To enhance piglet survival prospects, certain management interventions are used including cross-fostering to equalise or standardise litters, thus allowing fairer competition at the udder during suckling. When litter size routinely exceeds the ability of individual sows to successfully rear all the piglets (i.e., viable piglets outnumber functional teats), such fostering practices are essential but could be inadequate, meaning other interventions are deemed necessary. These include tooth reduction, split suckling, the use of nurse sow systems and early weaning, including split weaning, and use of artificial rearing systems. These practices raise welfare concerns for both parties, with piglet welfare discussed in Baxter and Edwards (Chapter 3: Piglet mortality and morbidity: inevitable or unacceptable?). Traditional cross-fostering practices can impact on the sow if performed too late and too often. If fostering of piglets occurs after a teat order has become established, it can lead to disturbance on the udder and termination of milk let-down, potentially causing stress for the sow. The use of foster mothers or nurse sows as a management solution to the problem of a large litter is now close to ubiquitous in Denmark. On average 15% of weaned sows in Danish herds are used as nurse sows after having nursed their own litter for 1–3 weeks (Pedersen, 2015). The two practices involving nurse sows are called one-step and two-step (Fig. 2.6). One-step management

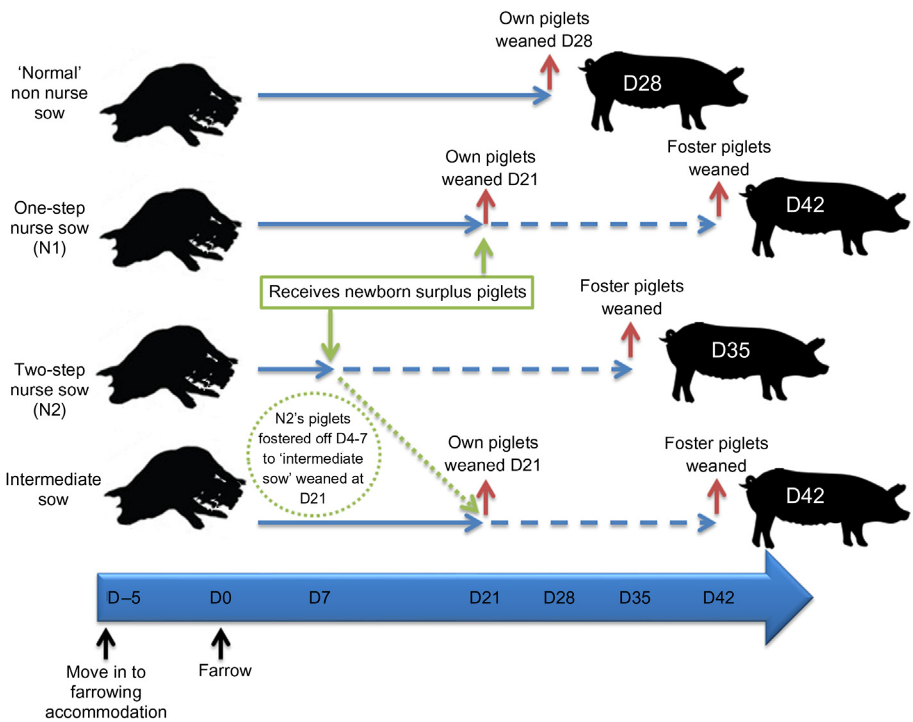

Figure 2.6 One- and two-step nurse strategies. Sows are moved in to farrowing accommodation 5 days before they are due to farrow (D-5). Lactation lengths vary depending on whether the sow is 'nonnurse,' N1 or N2 or intermediate.

involves weaning 21 day old piglets from a 'chosen' nurse sow and then fostering on surplus piglets from newly farrowed sows when the piglets are at least 6 hours old. Two-step management involves the use of more animals: an intermediate sow is identified and her litter is weaned at 28 days old (potentially at 21 days old) and a two-step nurse sow is identified whose piglets are 4−7 days old and are all then fostered onto the intermediate sow. The two-step sow is then given surplus, large newly farrowed piglets after colostrum intake (i.e., at least 6 hours old).

An immediately obvious welfare consequence for the nurse sow is that her confinement within the crate environment will be extended beyond the normal weaning period. This may raise issues for welfare relating to both the behavioural restriction associated with the crate and also to potential physical damage such as shoulder lesions, already described. For the one-step and intermediate sows, they are early weaned at the height of lactational output (approximately 21 days − Elsley, 1971) and are then expected to rear another litter for at least 21 or 14 days, respectively. For the two-step nurse sow, her own piglets are transferred after 4−7 days before having to rear another litter for potentially 28 days. If the intermediate sows litter is weaned at 28 days and she rears her foster litter for another 21 days, she has the potential for 49 days in a farrowing crate, not including the prefarrowing period after transfer from dry sow accommodation to the farrowing house. This extensive period of restriction prolongs lactational output, impacting on body condition, with potentially injurious consequences. In a cross-sectional study of 57 Danish commercial sow herds, Sørensen et al. (2016) reported higher levels of bursa on the legs and wounds on the udder in sows kept as nurse sows than nonnurse sows. There is also the potential for welfare impacts relating to lactational output and parent-offspring conflict. For example, early on in lactation the needs of the sow and her litter may be quite well aligned in terms of milk production, with the sow still investing energy in her current litter. However, during the latter stages of lactation the needs of the sow and her litter become increasingly dichotomised (see Section 2.2.2). The strategy adopted by the sow is one of balance; she must balance the needs of her current litter with the needs of any future litters and thus her reproductive success. Therefore, in order to maintain body condition whilst still providing for her current litter, she will reduce the number of milk let-downs per day. This can only be efficiently accomplished by a gradual separation from the litter, thus a control of her lactational output. In environments where the sow is kept loose for lactation, she is better able to control her output (Pajor et al., 1999). For the intermediate and one-step sow, she will be receiving a litter whose needs are very different to her own and are likely to impact on her future reproductive success. Evidence from Danish research lends support to this argument by demonstrating that nurse sows, on average, take one extra day to come on heat (Thorup, 2007). When a sow is transitioning to become a nurse sow, the limited literature available reports that she does not lactate for an extended period of time (3−12 hours), which is likely to cause significant discomfort in the udder and has been known to initiate lactational oestrus (Thorup, 2007). As superprolific breeding programmes persist, optimising management of nurse sows is likely to become an increasing focus for industry and researchers. How best to minimise the welfare impact on nurse sows should be prioritised and loose lactation systems could offer significant opportunities in this endeavour.

2.5.4 Feeding strategies

The selection of modern sows for increased mature body size and prolificacy (Section 2.3) has placed them under increasing metabolic pressure when meeting the nutrient needs for high milk production during lactation. If they are unable to meet these requirements from feed intake, they will catabolise their own body tissues to supply the necessary nutrients and rapidly lose body condition, with the associated welfare and production consequences discussed previously. Designing feeding strategies that are adapted to the different phases of farrowing and lactation is therefore equally important to housing design and management.

As with achieving optimum piglet survival, getting things right at the time of farrowing depends on a correct preparation during gestation (Mullan and Williams, 1989). Sows need to enter the farrowing accommodation neither too thin, limiting body reserves to draw on during the immediate postfarrowing period when feed intake is low, nor too fat, as this make sows more clumsy and liable to crush piglets and will reduce their voluntary food intake during the lactation period. A high fibre diet during gestation will help to promote intake in lactation, by accustoming the gut to higher volume of feed (Vestergaard and Danielsen, 1998; Quesnel et al., 2009). Inclusion of fibre in the immediate prefarrowing period will also help to reduce constipation which can occur at the time of farrowing and predispose sows to health problems such as MMA (Oliviero et al., 2009; Farmer et al., 1995), which can seriously impair welfare of both the sow and her litter. Fibre inclusion can also reduce sow restlessness in the postfarrowing period (Peltoniemi and Oliviero, 2015).

After farrowing, nutrient intake from feed needs to increase dramatically to keep pace with the requirements for milk production. To achieve this, the sow needs both a palatable and nutrient dense diet. Anything which detracts from voluntary feed intake potentially compromises sow welfare. Giving too much feed too soon after farrowing, however, can in some circumstances predispose sows to problems of MMA (Papadopoulos et al., 2010) and a phased increase over the first days before feeding fully to appetite may be necessary. This ensures that feed is always fresh and of good hygienic quality, rather than accumulating in the trough and becoming stale or mouldy in warm farrowing house conditions. Ensuring plentiful water availability is also very important as the newly farrowed sow is unwilling to work hard to obtain water from drinkers with a low flow rate, and will reduce both water and feed intake to suboptimal levels under these conditions (Leibbrandt et al., 2001). Drinkers should be able to supply two litres per minute and the quality of the water is also important. Another common problem which reduces feed intake is a high ambient temperature. Whilst a warm farrowing environment is important for piglet survival, it imposes stress on the sow who will reduce voluntary intake by 0.17 kg for every 1°C increase in temperature above 16°C (Black et al, 1993). Reducing farrowing room temperatures as piglets start to use locally heated creep areas, from the 22°C–20°C which is common at the time of farrowing to

18°C–16°C which is more comfortable for the sow, will have large benefits for feed intake. Avoiding heat stress can be a major challenge in some parts of the world, where ambient temperatures in summer often greatly exceed these values. In these circumstances, nutrient intake can be aided by providing feed little and often and at cooler times of the day and by formulating diets with lower thermogenic characteristics by using high fat and lower fibre content (Schoenherr et al., 1989). Providing localised cooling for the sow through water drip systems or cooling plates will also help (McGlone et al., 1988).

After 3 weeks of lactation, milk yield plateaus and starts to fall, while the appetite of the sow remains high and allows her to regain lost body condition in preparation for rebreeding. At the time of weaning, when lactation abruptly ceases, she is therefore accustomed to a high level of intake. It used to be believed that this would predispose mastitis, and severe feed restriction should be implemented at this time. However, it is now known that this is both unnecessary and indeed undesirable, as sustained high intake over this period is important for the number and quality of ova produced for the next litter (Hazeleger et al., 2005). Continued high level feeding also reduces aggression when sows are regrouped at weaning (Edwards et al., 1993).

2.5.5 Weaning age

As discussed in Section 2.2, under natural conditions the weaning of pigs from their mother is a gradual process that is complete by approximately 3–4 months of age (Jensen, 1988). However, due to economic considerations, the weaning age of pigs in commercial systems is much younger. Current EU legislation (Directive 2008/120/EC) specifies a minimum age at weaning of 28 days, except under specific conditions where pigs may be weaned from 21 days of age to facilitate all in-all out housing systems. In other parts of the world, weaning may be as early as 14 days, or even less if Segregated Early Weaning (SEW) is practised as a method of increasing postweaning performance by removing piglets from the sow whilst they are still under the protection of passive immunity, thereby reducing vertical transfer of pathogens, and minimising exposure to disease challenge postweaning (Maxwell and Sohn, 1999). Whilst weaning age has many implications for piglet welfare, there may also be consequences for sow welfare. The implications of extended lactation in confined conditions have been previously discussed for both sow physical condition (Section 2.5.3 on nurse sow challenges) and for the behavioural stress imposed by inability to escape the increasingly demanding litter (Section 2.2.2). However, less attention has been paid to the welfare implications of abrupt early weaning for the sow. On the day of weaning sows show increased restlessness and vocalisation (Sambraus and Baier, 2000) but this apparent agitation is relatively transient. The main focus of attention has been on the welfare challenge of reintegration into a sow group at the time of weaning. Under natural conditions, this takes place at approximately 2 weeks postpartum, when the sow leads her litter back to join the family group of related sows (Jensen and Redbo, 1987). It has been shown that aggression between sows remixed at this time in multisuckling systems is lower than that observed in newly weaned animals (see van Nieuwamerongen et al., 2014 for a review). Out of all of the alternatives, these group systems reflect the natural situation most accurately and score highly when considering sow welfare (Baxter et al., 2012). However, at present, they return highly variable performance figures and are particularly sensitive to poor management.

2.6 Conclusions and future trends

Although farrowing crates continue to predominate as the main maternity housing in most countries, there is momentum, in Europe at least, to investigate and trial alternative farrowing systems that allow the sow greater freedom of movement. A barometer for this change might be to look at the market and the increasing incidence of alternatives offered by companies specialising in pig buildings and housing systems. However many commercially available alternatives are temporary crate options. From a producer viewpoint these systems seem like an attractive prospect, as they offer little departure from the conventional crate and the crate remains as an 'insurance policy' if performance is poor when trialling zero confinement. There are also economic considerations in terms of investment. Although costs of alternative farrowing systems are rarely reported in the scientific literature (cf. Guy et al., 2012 for latest modelling estimates), those systems that increase space, operating on a larger footprint than the conventional crate, will have economic implications. These will include a capital investment to be returned and any other potential cost ramifications of increasing space per sow and litter (Guy et al., 2012). Temporary crates are the least costly, least risky 'alternative.' However temporary crates offer less in the way of improving sow welfare and, as these systems do not have design features to promote good maternal behaviour, it is likely that when operated with the sow completely free piglets will be at risk of crushing resulting from a combination of poor maternal behaviour and limited space. However, whilst temporary crating options may be perceived by farmers as a good introduction in to loose housing, such investment might be costly as was evident in the poultry industry with the issue of battery cages. The introduction of the 'enriched (or furnished) cage' to replace battery cages did not fully appreciate public perception that 'a cage is still a cage' and therefore a push for alternatives resulted in a surge in the free range market and development of barn egg and aviary alternatives. Any replacement of farrowing accommodation will involve significant investment. Future-proofing the system to satisfy the needs of all stakeholders, including the consumer, is important to ensure sustainability.

A more balanced equation where the cost of maternal investment (for instance shoulder lesions, loss of body condition and lower residual reproductive output and thus shorter longevity) is balanced against the increase in the number of piglets born and weaned, is needed as a basis for breeding programmes. Overall, there is a need for an increased understanding of maternal investment as a sensitive, biological system, continuously responding to any small change in the environment as well as in the genetic selection programme. Finally, the great demand on young sows giving birth to an increasing number of large piglets, asks for more specialised feeding regimes and an increased management effort by the farmer. The slight increase in the number of weaned piglets has to be weighed against all costs in the production system, including the extra time the farmer has to spend on surplus piglets that otherwise would have died or still die before the end of the lactation. At present this system is not fully understood, and this is also why we see too little progress in sow welfare and lack of sustainable and robust systems.

Abbreviations

AHDB Pork	Agriculture and Horticulture Development Board Pork
BPEX	British Pig Executive
EFSA	European Food Safety Authority

References

AHDB Pork, 2013. Interpig report. Pig cost of production in selected countries. AHDB Pork, Agriculture and Horticulture Development Board (AHDB), Stoneleigh, UK.

Ahlström, S., Jarvis, S., Lawrence, A.B., 2002. Savaging gilts are more restless and more responsive to piglets during the expulsive phase of parturition. Appl. Anim. Behav. Sci. 76, 83–91.

Algers, B., Jensen, P., 1985. Communication during suckling in the domestic pig. Effects of continuous noise. Appl. Anim. Behav. Sci. 14, 49–61.

Algers, B., Uvnäs-Moberg, K., 2007. Maternal behavior in pigs. Horm. Behav. 52, 78–85.

Algers, B., Madej, A., Rojanasthien, S., Uvnäs-Moberg, K., 1991. Quantitative relationships between suckling-induced teat stimulation and the release of prolactin, gastrin, somatostatin, insulin, glucagon and vasoactive intestinal polypeptide in sows. Vet. Res. Commun. 15, 395–407.

Alonso-Spilsbury, M., Mota-Rojas, D., Martínez-Burnes, J., Arch, E., López Mayagoitia, A., Ramírez-Necoechea, R., Olmos, A., Trujillo, M.E, 2004. Use of oxytocin in penned sows and its effect on fetal intra-partum asphyxia. Anim. Reprod. Sci. 84, 157–167. Available from: http://dx.doi.org/10.1016/j.anireprosci.2003.11.002.

Andersen, I.L., 2016. Production results on the "Sow comfort" farrowing pen for loose housed sows. 24th International Pig Veterinary Society Congress, Belfast, Northern Ireland, Abstract no. PO-PT2-259, p. 651.

Andersen, I.L., Berg, S., Bøe, K.E., 2005. Crushing of piglets by the mother sow (Sus scrofa) —purely accidental or a poor mother? Appl. Anim. Behav. Sci. 93, 229–243. Available from: http://dx.doi.org/10.1016/j.applanim.2004.11.015.

Andersen, I.L., Naevdal, E., Boe, K.E., Bakken, M., 2006a. The significance of theories in behavioural ecology for solving problems in applied ethology – possibilities and limitations. Appl. Anim. Behav. Sci. 97, 85–104.

Andersen, I.L., Berg, S., Bøe, K.E., Edwards, S., 2006b. Positive handling in late pregnancy and the consequences for maternal behaviour and production in sows. Appl. Anim. Behav. Sci. 99, 64–76. Available from: http://dx.doi.org/10.1016/j.applanim.2005.09.007.

Andersen, I.L., Tajet, G.M., Haukvik, I.A., Kongsrud, S., Bøe, K.E., 2007. Relationship between postnatal piglet mortality, environmental factors and management around farrowing in herds with loose-housed, lactating sows. Acta Agric. Scand. A Anim. Sci. 57, 38–45.

Andersen, I.L., Nævdal, E., Bøe, K.E., 2011. Maternal investment, sibling competition, and offspring survival with increasing litter size and parity in pigs (Sus scrofa). Behav. Ecol. Sociobiol. 65, 1159–1167. Available from: http://dx.doi.org/10.1007/s00265-010-1128-4.

Andersen, I.L., Vasdal, G., Pedersen, L.J., 2014. Nest building and posture changes and activity budget of gilts housed in pens and crates. Appl. Anim. Behav. Sci. 159, 29–33.

Arey, D.S., Petchey, A.M., Fowler, V.R., 1991. The preparturient behavior of sows in enriched pens and the effect of preformed nests. Appl. Anim. Behav. Sci. 31, 61–68.

Arey, D.S., Petchey, A.M., Fowler, V.R., 1992. The effect of straw on farrowing site choice and nest building behaviour in sows. Anim. Prod. 54, 129–133.

Bäckström, L., Algers, B., Nilsson, J., Ekesbo, I, 1994. Effects of sow housing on production and health. Proceedings of the 13th IPVS Congress, 26–30 June, Bangkok, Thailand, p. 427.

Barnett, J.L., 2007. Effects of confinement and research needs to underpin welfare standards. J. Vet. Behav. 2, 213–218.

Bates, R.O., Edwards, D.B., Korthals, R.L., 2003. Sow performance when housed either in groups with electronic sow feeders or stalls. Livest. Prod. Sci. 79, 29–35. Available from: http://dx.doi.org/10.1016/S0301-6226(02)00119-7.

Baumgartner, J., 2011. Pig industry in CH, CZ, DE, DK, NL, NO, SE, UK, AT and EU. IN: Baumgartner, J. [Hrsg.]. Report of the free farrowing workshop Vienna 2011. Wien, Vetmeduni Vienna, pp. 3–7. ISBN: 978-3-9502915-3-7.

Baxter, E.M., Jarvis, S., Sherwood, L., Robson, S.K., Ormandy, E., Farish, M., Smurthwaite, K.M., Roehe, R., Lawrence, A.B., Edwards, S.A., 2009. Indicators of piglet survival in an outdoor farrowing system. Livest. Sci. 124 (1–3), 266–276. Available from: http://dx.doi.org/10.1016/j.livsci.2009.02.008.

Baxter, E.M., Lawrence, A.B., Edwards, S.A., 2011. Alternative farrowing systems: design criteria for farrowing systems based on the biological needs of sows and piglets. Animal. 5, 580–600. Available from: http://dx.doi.org/10.1017/s1751731110002272.

Baxter, E.M., Lawrence, A.B., Edwards, S.A., 2012. Alternative farrowing accommodation: welfare and economic aspects of existing farrowing and lactation systems for pigs. Animal. 6, 96–117. Available from: http://dx.doi.org/10.1017/s1751731111001224.

Baxter, E.M., Adeleye, O.O., Jack, M.C., Farish, M., Ison, S.H., Edwards, S.A., 2015. Achieving optimum performance in a loose-housed farrowing system for sows: the effects of space and temperature. Appl. Anim. Behav. Sci. 169, 9–16. Available from: http://dx.doi.org/10.1016/j.applanim.2015.05.004.

Baxter, E.M., Rutherford, K.M.D., D'Eath, R.B., Arnott, G., Turner, S.P., Sandøe, P., Moustsen, V.A., Thorup, F., Edwards, S.A., Lawrence, A.B., 2013. The welfare implications of large litter size in the domestic pig II: management factors. Anim. Welfare. 22, 219–238. Available from: http://dx.doi.org/10.7120/09627286.22.2.219.

Baxter, S.H., 1983a. Biology into buildings. In: Baxter, S.H., Baxter, M.R., MacCormack, J. A.C. (Eds.), Farm Animal Housing and Welfare. Martinus Nijhoff Publishers, Netherlands, pp. XI–XVI.

Baxter, M.R., 1983b. Housing and welfare from first principles. In: Baxter, S.H., Baxter, M.R., MacCormack, J.A.C. (Eds.), Farm Animal Housing and Welfare. Martinus Nijhoff Publishers, Netherlands.

Baxter, M.R., 1991. The freedom farrowing system. Farm Build. Progr. 104, 9–15.

Baxter, E.M., Edwards, S.A., 2017. Piglet mortality and morbidity: inevitable or unacceptable? In: Špinka, M. (Ed.), Advances in Pig Welfare. Woodhead Publishing, Duxford, UK.

Baxter, M.R., Schwaller, C., 1983. Space requirements for sows in confinement. In: Baxter, S.H., Baxter, M.R., MacCormack, J.A.D. (Eds.), Farm Animal Housing and Welfare. Martinus Nijhoff Publishers, The Hague, The Netherlands, pp. 181−195.

Black, J.L., Mullan, B.P., Lorschy, M.L., Giles, L.R., 1993. Lactation in the sow during heat stress. Livest. Product. Sci. 35, 153−170. Available from: http://dx.doi.org/10.1016/0301-6226(93)90188-n.

Blackshaw, J., Blackshaw, A., Thomas, F., Newman, F., 1994. Comparison of behaviour patterns of sows and litters in a farrowing crate and a farrowing pen. Appl. Anim. Behav. Sci. 39, 281−295.

Blasco, A., Bidanel, J.P., Haley, C.S., 1995. Genetics and neonatal survival. In: Varley, M.A. (Ed.), The Neonatal Pig: Development and Survival. CABI, Wallingford, pp. 17−38.

Bohnenkamp, Anna-Lena, Meyer, Christian, Müller, Karin, Krieter, Joachim, 2013. Group housing with electronically controlled crates for lactating sows. Effect on farrowing, suckling and activity behavior of sows and piglets. Appl. Anim. Behav. Sci. 145, 37−43. Available from: http://dx.doi.org/10.1016/j.applanim.2013.01.015.

Bonde, M., 2008. Prevalence of decubital shoulder lesions in Danish sow herds. Internal Report 12, Faculty of Agricultural Sciences, University of Aarhus, Denmark.

Bøe, K., 1991. The process of weaning in pigs: when the sow decides. Appl. Anim. Behav. Sci. 30 (1−2), 47−59.

Bøe, K., 1993. The effect of age at weaning and post-weaning environment on the behaviour of pigs. Acta Agric. Scand. A Anim. Sci. 43, 173−180.

BPEX (British Pig Executive), 2004. An industry update on farrowing systems. Milton Keynes.

BPEX, 2011. 20:20 Pig health and welfare: a vision for 2020. BPEX, Stoneleigh.

Bradshaw, R.H., Broom, D.M., 1999. A comparison of the behaviour and performance of sows and piglets in crates and oval pens. Anim. Sci. 69, 327−333.

Cassar, G., Kirkwood, R.N., Friendship, R., Poljak, Z., 2005. Sow and litter performance following farrowing induction with prostaglandin: effect of adjunct treatments with dexamethasone or oxytocin. J. Swine Health Prod. 13, 81−85.

Castrén, H., Algers, B., de Passillé, A., Rushen, J., Uvnäs-Moberg, K., 1993a. Preparturient variation in progesterone, prolactin, oxytocin and somatostatin in relation to nest building in sows. Appl. Anim. Behav. Sci. 38, 91−102.

Castrén, H., Algers, B., de Passillé, A., Rushen, J., Uvnäs-Moberg, K., 1993b. Early milk ejection, prolonged parturition and periparturient oxytocin release in the pig. Anim. Sci. 57, 465−471.

Chantaraprateep, P., Prateep, P., Lohachit, C., Kunavongkrit, A., Poomsuwan, P., 1986. Investigation into the use of prostaglandin F2α (PGF2α:) and oxytocin for the induction of farrowing. Aust. Vet. J. 63, 254−256.

Chidgey, K., Morel, P., Stafford, K., Barugh, I., 2016. Observations of sows and piglets housed in farrowing pens with temporary crating or farrowing crates on a commercial farm. Appl. Anim. Behav. Sci. 176, 12−18.

Collins, E.R., Kornegay, E.T., Bonnette, E.D., 1987. The effects of two confinement systems on the performance of nursing sows and their litters. Appl. Anim. Behav. Sci. 17, 51−59.

Council Directive 2008/120/EC of 18 December 2008 laying down minimum standards for the protection of pigs (codified version).

Cronin, G.M., Barnett, J.L., Hodge, F.M., Smith, J.A., Mccallum, T.H., 1991. The welfare of pigs in 2 farrowing lactation environments – cortisol responses of sows. Appl. Anim. Behav. Sci. 32, 117–127.

Cronin, G.M., Dunsmore, B., Leeson, E., 1998. The effects of farrowing nest size and width on sow and piglet behaviour and piglet survival. Appl. Anim. Behav. Sci. 60, 331–345. Available from: http://dx.doi.org/10.1016/s0168-1591(98)00159-2.

Cronin, G.M., Lefebure, B., McClintock, S., 2000. A comparison of piglet production and survival in the Werribee Farrowing Pen and conventional farrowing crates at a commercial farm. Aust. J. Exp. Agr. 40, 17–23.

Damm, B.I., Pedersen, L.J., 2000. Eliminative behaviour in pre-parturient gilts previously kept in pens or stalls. Acta Agric. Scand. A Anim. Sci. 50, 316–320.

Damm, B.I., Bildsøe, M., Gilbert, C., Ladewig, J., Vestergaard, K.S., 2002. The effects of confinement on periparturient behaviour and circulating prolactin, prostaglandin F2 [alpha] and oxytocin in gilts with access to a variety of nest materials. Appl. Anim. Behav. Sci. 76, 135–156.

Damm, B.I., Pedersen, L.J., Marchant-Forde, J.N., Gilbert, C.L., 2003. Does feed-back from a nest affect periparturient behaviour, heart rate and circulatory cortisol and oxytocin in gilts?. Appl. Anim. Behav. Sci. 83, 55–76. Available from: http://dx.doi.org/10.1016/s0168-1591(03)00111-4.

Danish Agriculture and Food Council, 2016. Benchmarking of standards. <http://www.agricultureandfood.co.uk/knowledge-bank/benchmark>.

Dawkins, M.S., 1998. Evolution and animal welfare. Q. Rev. Biol. 73, 305–328.

DEFRA, 2003. Code of recommendations for the welfare of livestock: pigs. DEFRA Publications, London.

Dial, G.D., Almond, G.W., Hilley, H.D., Repasky, R.R., Hagan, J., 1987. Oxytocin precipitation of prostaglandin-induced farrowing in swine: determination of the optimal dose of oxytocin and optimal interval between prostaglandin F2α and oxytocin. Am. J. Vet. Res. 48, 966–970.

Downey, B.R., Conlon, P.D., Irvine, D.S., Baker, R.D., 1976. Controlled farrowing program using a prostaglandin analogue, AY24,655. Can. J. Anim. Sci. 56, 655–659.

Edwards, S.A., 1998. Nutrition of the rearing gilt and sow. In: Wiseman, J., Varley, M.A., Chadwick, J.P. (Eds.), Progress in Pig Science. Nottingham University Press, Nottingham, pp. 361–381.

Edwards, S.A., 2002. Perinatal mortality in the pig: environmental or physiological solutions? Livest. Product. Sci. 78 (1), 3–12. Available from: http://dx.doi.org/10.1016/s0301-6226(02)00180-x.

Edwards, S.A., Fraser, D., 1997. Housing systems for farrowing and lactation. Pig J. 39, 77–89.

Edwards, S.A., Mauchline, S., Stewart, A.H., 1993. Designing pens to minimise aggression when sows are mixed. Farm Build. Prog. 113, 20–23.

Edwards, S.A., Armsby, A.W., Large, J.W., 1998. Effects of feed station design on the behaviour of group-housed sows using an electronic individual feeding system. Livest. Prod. Sci. 19, 511–522.

Edwards SA, Seddon Y, Rogusz A, Brett M, Ross D, Baxter EM., 2012. Optimising nest design for the PigSAFE free farrowing pen. Proceedings of the 46th Congress of the International Society for Applied Ethology, 31 July–4 August 2012, Vienna, Austria, p. 95.

EFABAR, 2007. The code of good practice for farm animal breeding and reproduction. <http://www.effab.info/>.

Elsley,, F.W.H., 1971. Nutrition and lactation in sows. In: Faulkner, I.R. (Ed.), Lactation. Butterworths, London, pp. 393–411.

Engblom, L., Lundeheim, N., Schneider, M.D.P., Dalin, A.M., Andersson, K., 2009. Genetics of crossbred sow longevity. Animal. 3, 783–790. Available from: http://dx.doi.org/10.1017/S175173110900411X.

Engblom, L., Calderón Díaz, J.A., Nikkil, M., Gray, K., Harms, P., Fix, J., Tsuruta, S., Mabry, J., Stalder, K., 2016. Genetic analysis of sow longevity and sow lifetime reproductive traits using censored data. J. Anim. Breed. Genet. 133, 138–144.

English, P.R., Smith, W.J., MacLean, A., 1977. The sow: improving her efficiency. Farming Press Limited, Ipswich.

English, P.R., Grant, S.A., McPherson, O., Edwards, S.A., 1999. Evaluation of the effects of the positive 'befriending' of sows and gilts ('pleasant' treatment) prior to parturition and in early lactation on sow behaviour, the process of parturition and piglet survival. In: Russel, A.J.F., Morgan, C.A., Savory, C.J., Appleby, M.C., Lawrence, T.L.J. (Eds.), Farm Animal Welfare—Who Writes the Rules? Proceedings of an International Symposium Organized by The British Society of Animal Science. Occasional Publication—British Society of Animal Science, Edinburgh, UK, pp. 132–136.

European Food Safety Authority, 2007. Animal health and welfare aspects of different housing and husbandry systems for adult breeding boars, pregnant, farrowing sows and unweaned piglets [1], pp. 1–13. Scientific Opinion of the Panel on Animal Health and Welfare, EFSA.

Farmer, C., Robert, S., Matte, J.J., Girard, C.L., Martineau, G.P., 1995. Endocrine and peripartum behavioral responses of sows fed high-fiber diets during gestation. Can. J. Anim. Sci. 75, 531–536.

Forbes, L.S., Mock, D.W., 1998. Parental optimism and progeny choice: when is screening for offspring quality affordable. J. Theor. Biol. 192, 3–14. Available from: http://dx.doi.org/10.1006/jtbi.1997.0596.

Frädrich, H., 1974. A comparison of behaviour in the Suidae. New Series. 24, 133–143, IUCN, Morges.

Fraser, D., Kramer, D.L., Pajor, E.A., Weary, D.M., 1995. Conflict and cooperation: sociobiological principles and the behaviour of pigs. Appl. Anim. Behav. Sci. 44, 139–157.

Gilbert, C.L., 1999. Oxytocin secretion and management of parturition in the pig. Reprod. Domest. Anim. 34, 193–200.

Goetz, M., Troxler, J., 1995. Group housing of sows during farrowing and lactation. Trans. ASAE. 38, 1495–1500.

Gonyou, H.W., 1996. Water use and drinker management. Prairie Swine Centre, Saskatoon.

Gourdine, J.L., De Greef, K.H., Rydhmer, L., 2010. Breeding for welfare in outdoor pig production: a simulation study. Livest. Sci. 132, 26–34.

Graves, H.B., 1984. Behavior and ecology of wild and feral swine (Sus scrofa). J. Anim. Sci. 58, 482–492.

Grissom, K.K., Friend, T.H., Dellmeier, G.R., Knabe, D.A., Dahm, P.F., 1990. Effects of various farrowing systems on piglet survivability. J. Anim. Sci. 68, 253.

Gu, Z., Gao, Y., Lin, B., Zhong, Z., Liu, Z., Wang, C., Li, B., 2011. Impacts of a freedom farrowing pen design on sow behaviours and performance. Prev. Vet. Med. 102 (4), 296–303.

Gundlach, H., 1968. Brutfürsorge, Brutpflege, Verhaltensontogenese und Tagesperiodik beim Europäischen Wildschwein. Z. Tierpsychol. 25, 955–995.

Gustafsson, L., Sutherland, W.J., 1988. The costs of reproduction in the collared flycatcher *Ficedula albicollis*. Nature. 335, 813–815.

Gustafsson, M., Jensen, P., De Jonge, F.H., Illmann, G., Špinka, M., 1999. Maternal behaviour of domestic sows and crosses between domestic sows and wild boar. Appl. Anim. Behav. Sci. 65, 29–42.

Guy, J.H., Cain, P.J., Seddon, Y.M., Baxter, E.M., Edwards, S.A., 2012. Economic evaluation of high welfare indoor farrowing systems for pigs. Anim. Welf. 21, 19.

Hales, J., Moustsen, V.A., Nielsen, M.B.F., Hansen, C.F., 2014. Higher preweaning mortality in free farrowing pens compared with farrowing crates in three commercial pig farms. Animal. 8, 113–120.

Hales, J., Moustsen, V.A., Nielsen, M.B.F., Hansen, C.F., 2015. Temporary confinement of loose-housed hyperprolific sows reduces piglet mortality. J. Anim. Sci. 93, 4079–4088.

Hazeleger, W., Soede, N.M., Kemp, B., 2005. The effect of feeding strategy during the prefollicular phase on subsequent follicular development in the pig. Domest. Anim. Endocrinol. 29, 362–370.

Hemsworth, P.H., Barnett, J.L., 1992. The effects of early contact with humans on the subsequent level of fear of humans in pigs. Appl. Anim. Behav. Sci. 35, 83–90.

Hemsworth, P.H., Coleman, G.J., Cronin, G.M., Spicer, E.M., 1995. Human care and the neonatal pig. In: Varley, M.A. (Ed.), The Neonatal Piglet: Development and Survival. CAB International, Wallingford, pp. 313–331.

Hemsworth, P.H., Pedersen, V., Cox, M., Cronin, G.M., Coleman, G.J., 1999. A note on the relationship between the behavioural response of lactating sows to humans and the survival of their piglets. Appl. Anim. Behav. Sci. 65, 43–52. Available from: http://dx.doi.org/10.1016/s0168-1591(99)00047-7.

Herskin, M.S., Bonde, M.K., Jørgensen, E., Jensen, K.H., 2011. Decubital shoulder ulcers in sows: a review of classification, pain and welfare consequences. Animal. 5, 757–766.

Honeyman, M.S., Roush, W.B., Penner, A.D., 1998. Pig crushing mortality by hut type in outdoor farrowing. Annual Progress Report. Iowa State University, Ames, pp. 16–17.

Hunt, K., Petchey, A.M., 1987. A study of the environmental preferences of sows around farrowing. Farm Build. Progr. 89, 11–14.

Ison, S., Clutton, R., Di Giminiani, P., Rutherford, K., 2016. A review of pain assessment in pigs. Front. Vet. Sci. 3, 108.

Ison, S.H., Wood, C.M., Baxter, E.M., 2015. Pre-pubertal gilt behaviour during human interaction and startle object tests and the relationship with farrowing in conventional crates or PigSAFE pens. Appl. Anim. Behav. Sci. 170, 26–33.

Janczak, A.M., Pedersen, L.J., Bakken, M., 2003. Aggression, fearfulness and coping styles in female pigs. Appl. Anim. Behav. Sci. 81 (1), 13–28. Available from: http://dx.doi.org/10.1016/s0168-1591(02)00252-6.

Jarvis, S., Lawrence, A.B., McLean, K.A., Chirnside, J., Deans, L.A., Calvert, S.K., 1998. The effect of environment on plasma cortisol and β-endorphin in the parturient pig and the involvement of endogenous opioids. Anim. Reprod. Sci. 52, 139–151.

Jarvis, S., Lawrence, A.B., Mclean, K.A., Deans, L.A., Chirnside, J., Calvert, S.K., 1999. The effect of piglet expulsion in the sow on plasma cortisol, adrenocorticotropic hormone and beta-endorphin. Reprod. Domest. Anim. 34, 89–94.

Jarvis, S., Reed, B.T., Lawrence, A.B., Calvert, S.K., Stevenson, J., 2004. Peri-natal environmental effects on maternal behaviour, pituitary and adrenal activation, and the progress of parturition in the primiparous sow. Anim. Welf. 13, 171–181.

Jensen, P., 1986. Observations on the maternal behaviour of free-ranging domestic pigs. Appl. Anim. Behav. Sci. 16, 131–142.

Jensen, P., 1988. Maternal behaviour of free-ranging domestic pigs. 1. Result of a three-year study. Report 23. Swedish University of Agricultural Sciences, Skara, p. 56.

Jensen, P., 1993. Nest-building in domestic sows: the role of external stimuli. Anim. Behav. 45, 351–358.

Jensen, P., 2002. Behaviour of pigs. In: Jensen, P. (Ed.), The Ethology of Domestic Animals. CABI Publishing, Wallingford, pp. 159–172.

Jensen, P., Recén, B., 1989. When to wean: observations from free-ranging domestic pigs. Appl. Anim. Behav. Sci. 23, 49–60.

Jensen, P., Redbo, I., 1987. Behaviour during nest leaving in free-ranging domestic pigs. Appl. Anim. Behav. Sci. 18, 355–362.

Jensen, P., Toates, F.M., 1993. Who needs 'behavioural needs'? Motivational aspects of the needs of animals. Appl. Anim. Behav. Sci. 37, 161–181.

Kanis, E., de Greef, K.H., Hiemstra, A., van Arendonk, J.A.M., 2005. Breeding for societally important traits in pigs. J. Anim. Sci. 83, 948–957.

Kerr, J.C., Cameron, N.D., 1995. Reproductive performance of pigs selected for components of efficient lean growth. Animal Science. 60, 281–290. Available from: http://dx.doi.org/10.1017/s1357729800008444.

Kerr, S.G.C., Wood-Gush, D.G.M., Moser, H., Whittemore, C.T., 1988. Enrichment of the production environment and the enhancement of welfare through the use of the Edinburgh Family Pen System of pig production. Res. Develop. Agr. 5, 171–186.

Kirkden, R.D., Broom, D.M., Andersen, I.L., 2013. Piglet mortality: the impact of induction of farrowing using prostaglandins and oxytocin. Anim. Reprod. Sci. 138, 14–24.

Kirkwood, R.N., Thacker, P.A., Aherne, F.X., Goonewardene, L.A., 1996. The effect of dose and route of administration of prostaglandin F2α on the parturient response of sows. Swine Health Prod. 4, 123–126.

Knap, P.W., 2005. Breeding robust pigs. Aust. J. Exp. Agr. 45 (7–8), 763–773.

Krebs, J.R., Kacelnik, A., 1991. Decision making. In: Krebs, J.R., Davies, N.B. (Eds.), Behavioural Ecology: An Evolutionary Approach. Blackwell Scientific Publishers, Oxford, pp. 105–137.

Kruschwitz, A., Zupan, M., Buchwalder, T., Huber-Eicher, B., 2008. Nest preference of laying hens (*Gallus gallus domesticus*) and their motivation to exert themselves to gain nest access. Appl. Anim. Behav. Sci. 112, 321–330.

Lawrence, A.B., Petherick, J.C., Mclean, K., Gilbert, C.L., Chapman, C., Russell, J.A., 1992. Naloxone prevents interruption of parturition and increases plasma oxytocin following environmental disturbance in parturient sows. Physiol. Behav. 52, 917–923.

Lawrence, A.B., Petherick, J.C., McLean, K.A., Deans, L.A., Chirnside, J., Gaughan, A., Clutton, E., Terlouw, E.M.C., 1994. The effect of environment on behaviour, plasma cortisol and prolactin in parturient sows. Appl. Anim. Behav. Sci. 39, 313–330. Available from: http://dx.doi.org/10.1016/0168-1591(94)90165-1.

Leibbrandt, V.D., Johnston, L.J., Shurson, G.C., Crenshaw, J.D., Libal, G.W., Arthur, R.D., 2001. Effect of nipple drinker water flow rate and season on performance of lactating swine. J. Anim. Sci. 79, 2770–2775.

Lensink, B., Leruste, H., De Bretagne, T., Bizeray-Filoche, D., 2009. Sow behaviour towards humans during standard management procedures and their relationship to piglet survival. Appl. Anim. Behav. Sci. 119, 151–157.

Lessells, C.M., 1991. The evolution of life histories. In: Krebs, J.R., Davies, N.B. (Eds.), Behavioural Ecology: An Evolutionary Approach. Blackwell, Oxford, pp. 32–65.

Lou, Z.S., Hurnik, J.F., 1994. An ellipsoid farrowing crate – its ergonomic design and effects on pig productivity. J. Anim. Sci. 72, 2610–2616.

Lundeheim, N., Lundgren, H., Rydhmer, L., 2014. Shoulder ulcers in sows are genetically correlated to leanness of young pigs and to litter weight. Acta Agric. Scand. A Anim. Sci. 64, 67–72.

Lundgren, H., Zumbach, B., Lundeheim, N., Grandinson, K., Vangen, O., Olsen, D., Rydhmer, L., 2011. Heritability of shoulder ulcers and genetic correlations with mean piglet weight and sow body condition. Animal. 6, 1–8.

MacLean, C.W., 1968. The thin sow problem. Vet. Rec. 83, 308–316.

Mainau, E., Manteca, X., 2011. Pain and discomfort caused by parturition in cows and sows. Appl. Anim. Behav. Sci. 135, 241–251. Available from: http://dx.doi.org/10.1016/j.applanim.2011.10.020.

Marchant, J.N., Broom, D.M., Corning, S., 2001. The influence of sow behaviour on piglet mortality due to crushing in an open farrowing system. Anim. Sci. 72, 19–28.

Marchant, J.N., Rudd, A.R., Mendl, M.T., Broom, D.M., Meredith, M.J., Corning, S., Simmins, P.H., 2000. Timing and causes of piglet mortality in alternative and conventional farrowing systems. Vet. Rec. 147, 209–214. Available from: http://dx.doi.org/10.1136/vr.147.8.209.

Marchant Forde, J.N., 2002. Piglet- and stockperson-directed sow aggression after farrowing and the relationship with a pre-farrowing, human approach test. Appl. Anim. Behav. Sci. 75, 115–132. Available from: http://dx.doi.org/10.1016/s0168-1591(01)00170-8.

Mattsson B 1996. Digivande suggor i grupp. Slakteriförbundets FoU-grupp Svin. In Report no. 9 Scan, p. 16.

Maxwell, C.V., Sohn, K.S., 1999. The pros and cons of SEW system – Review. Asian – Australasian. J. Anim. Sci. 12, 226–232.

McGlone, J.J., 2006. Comparison of sow welfare in the Swedish deep-bedded system and the US crated-sow system. J. Am. Vet. Med. Assoc. 229, 1377–1380.

McGlone, J.J., Stansbury, W.F., Tribble, L.F., 1988. Management of lactating sows during heat stress: effects of water drip, snout coolers, floor type and a high energy-density diet. J. Anim. Sci. 66, 885–891.

McLean, K.A., Lawrence, A.B., Petherick, J.C., Deans, L., Chirnside, J., Vaughan, A., Nielsen, B.L., Webb, R., 1998. Investigation of the relationship between farrowing environment, sex steroid concentrations and maternal aggression in gilts. Anim. Reprod. Sci. 50, 95–109. Available from: http://dx.doi.org/10.1016/s0378-4320(97)00088-2.

Meat and Livestock Commission/BPEX 2000-2015, The Pig Yearbooks 2000-2015.

Melisova, M., Illmann, G., Chaloupkova, H., Bozdechova, B., 2014. Sow postural changes, responsiveness to piglet screams, and their impact on piglet mortality in pens and crates. J. Anim. Sci. 92, 3064–3072.

Mota-Rojas, D., Martinez-Burnes, J., Trujillo-Ortega, M.E., Alonso-Spilsbury, M.L., Ramirez-Necoechea, R., Lopez, A., 2002. Effect of oxytocin treatment in sows on umbilical cord morphology, meconium staining, and neonatal mortality of piglets. Am. J. Vet. Res. 63, 1571–1574. Available from: http://dx.doi.org/10.2460/ajvr.2002.63.1571.

Mota-Rojas, D., Trujillo, M.E., Martínez, J., Rosales, A.M., Orozco, H., Ramírez, R., Necoechea, R., Lopez, A., 2006. Comparative routes of oxytocin administration in crated farrowing sows and its effects on fetal and postnatal asphyxia. Anim. Reprod. Sci. 92, 123–143. Available from: http://dx.doi.org/10.1016/j.anireprosci.2005.04.012.

Moustsen, V.A., Lahrmann, H.P., D'Eath, R.B., 2011. Relationship between size and age of modern hyper-prolific crossbred sows. Livest. Sci. 141, 272–275.

Moustsen, V.A., Hales, J., Lahrmann, H.P., Weber, P.M., Hansen, C.F., 2013. Confinement of lactating sows in crates for 4 days after farrowing reduces piglet mortality. Animal. 7, 648–654.

Mullan, B.P., Williams, I.H., 1989. The effect of body reserves at farrowing on the reproductive performance of first-litter sows. Anim. Prod. 48, 449–457.

Muns, R., Manteca, X., Gasa, J., 2015. Effect of different management techniques to enhance colostrum intake on piglet's growth and mortality. Anim. Welf. 92, 1193–1199.

Newberry, R.C., Woodgush, D.G.M., 1985. The suckling behavior of domestic pigs in a semi-natural environment. Behaviour. 95, 11–25.

Nicol, C.J., Caplen, G., Edgar, J., Browne, W.J., 2009. Associations between welfare indicators and environmental choice in laying hens. Anim. Behav. 78, 413–424.

Ocepek, M., Andersen, I., 2017. What makes a good mother? Maternal behavioural traits important for piglet survival. Appl. Anim. Behav. Sci.

Ocepek, M., Andersen-Ranberg, I., Edwards, S., Fredriksen, B., Framstad, T., Andersen, I., 2016. Can a super sow be a robust sow? Consequences of litter investment in purebred and crossbred sows of different parities. J. Anim. Sci. 94, 3550.

Ocepek, M., Newberry, R.C., Andersen, I.L., 2017. Trade-offs between litter size and offspring fitness in domestic pigs subjected to different genetic selection pressures. Appl. Anim. Behav. Sci. 193, 7–14.

Oliviero, C., Heinonen, M., Valros, A., Halli, O., Peltoniemi, O.A., 2008. Effect of the environment on the physiology of the sow during late pregnancy, farrowing and early lactation. Anim. Reprod. Sci. 105, 365–377.

Oliviero, C., Kokkonen, T., Heinonen, M., Sankari, S., Peltoniemi, O., 2009. Feeding sows with high fibre diet around farrowing and early lactation: impact on intestinal activity, energy balance related parameters and litter performance. Res. Vet. Sci. 86, 314–319.

Oliviero, C., Heinonen, M., Valros, A., Peltoniemi, O., 2010. Environmental and sow-related factors affecting the duration of farrowing. Anim. Reprod. Sci. 119, 85–91.

Pajor, E.A., Weary, D.M., Fraser, D., Kramer, D.L., 1999. Alternative housing for sows and litters: 1. Effects of sow-controlled housing on responses to weaning. Appl. Anim. Behav. Sci. 65, 105–121.

Pajor, E.A., Weary, D.M., Caceres, C., Fraser, D., Kramer, D.L., 2002. Alternative housing for sows and litters: Part 3. Effects of piglet diet quality and sow-controlled housing on performance and behaviour. Appl. Anim. Behav. Sci. 76, 267–277.

Papadopoulos, G.A., Vanderhaeghe, C., Janssens, G.P., Dewulf, J., Maes, D.G., 2010. Risk factors associated with postpartum dysgalactia syndrome in sows. Vet. J. 184, 167–171.

Pedersen, L.J., 2015, Neonatal piglet mortality in relation to sow farrowing environment. In Proceedings of the International Conference on Pig Welfare: Improving Pig Welfare – What are the Ways Forward? Copenhagen. 26–29.

Pedersen, L.J., 2017. Overview of commercial pig production systems and their main welfare challenges. In: Špinka, M. (Ed.), Advances in Pig Welfare. Woodhead Publishing, Duxford, UK.

Pedersen, L.J., Damm, B.I., Marchant-Forde, J.N., Jensen, K.H., 2003. Effects of feed-back from the nest on maternal responsiveness and postural changes in primiparous sows during the first 24 h after farrowing onset. Appl. Anim. Behav. Sci. 83, 109–124.

Pedersen, L.J., Jørgensen, E., Heiskanen, T., Damm, B.I., 2006. Early piglet mortality in loose-housed sows related to sow and piglet behaviour and to the progress of parturition. Appl. Anim. Behav. Sci. 96, 215–232. Available from: http://dx.doi.org/10.1016/j.applanim.2005.06.016.

Pedersen, L.J., Berg, P., Jorgensen, G., Andersen, I.L., 2011a. Neonatal piglet traits of importance for survival in crates and indoor pens. J. Anim. Sci. 89 (4), 1207–1218. Available from: http://dx.doi.org/10.2527/jas.2010-3248.

Pedersen, M.L., Moustsen, V.A., Nielsen, M.B.F., Kristensen, A.R., 2011b. Improved udder access prolongs duration of milk letdown and increases piglet weight gain. Livest. Sci. 140, 253–261.

Peltoniemi, O.A.T., Oliviero, C., 2015. Housing, management and environment during farrowing and early lactation. In: Farmer, C. (Ed.), In: The Gestating and Lactating Sow. Wageningen Academic Publishers, Wageningen, pp. 77–84.

Petherick, J.C., 1983. A biological basis for the design of space in livestock housing. In: Baxter, S.H., Baxter, M.R., MacCormack, J.A.D. (Eds.), Farm Animal Housing and Welfare. Martinus Nijhoff Publishers, The Hague, The Netherlands, pp. 103–121.

Phillips PA and Fraser D, 1993. Developments in farrowing housing for sows and litters. Pig News and Information, 51N-55N.

Pitts, A.D., Weary, D.M., Fraser, D., Pajor, E.A., Kramer, D.L., 2002. Alternative housing for sows and litters.: Part 5. Individual differences in the maternal behaviour of sows. Appl. Anim. Behav. Sci. 76, 291–306.

Price, E.O., 1984. Behavioral aspects of animal domestication. Q. Rev. Biol. 59, 1–32.

Price, E.O., 1999. Behavioral development in animals undergoing domestication. Appl. Anim. Behav. Sci. 65, 245–271.

Prunier, A., Tallet, C., 2015. Endocrine and behavioural responses of sows to human interactions and consequences on reproductive performance. In: Farmer, C. (Ed.), The Gestating and Lactating Sow. Wageningen Academic Publishers, Wageningen, the Netherlands, pp. 279–295.

Quesnel, H., Meunier-Salaün, M.C., Hamard, A., Guillemet, R., Etienne, M., Farmer, C., Dourmad, J.Y., Père, M.C., 2009. Dietary fiber for pregnant sows: influence on sow physiology and performance during lactation. J. Anim. Sci. 87, 532–543.

Ritter, L.A., Xue, J., Dial, G.D., Morrison, R.B., Marsh, W.E., 1999. Prevalence of lesions and body condition scores among female swine at slaughter. J. Am. Vet. Med. Assoc. 214, 525–528.

Robertson, H.A., King, G.J., Elliot, J.I., 1978. Control of the time of parturition in sows with prostaglandin F2α. Can. J. Comp. Med. 42, 32–34.

Robertson, J.B., Laird, R., Hall, J.K.S., Forsyth, R.J., Thomson, J.M., Walker-Love, J., 1966. A comparison of two indoor farrowing systems for sows. Anim. Prod. 8, 171–178. Available from: http://dx.doi.org/10.1017/s0003356100034553.

Roehe, R., 1999. Genetic determination of individual birth weight and its association with sow productivity using Bayesian analyses. J. Anim. Sci. 77, 330–343.

Roguet, C., Renaud, H., Duflot, B., 2011. Productivité du travail en elevage porcin: comparaison européenne et facteurs de variation. Journees de la Recherche Porcine en France. 43, 251–252.

Rosvold, E.M., Kielland, C., Ocepek, M., Framstad, T., Fredriksen, B., Andersen-Ranberg, I., Næss, G., Andersen, I.L., 2017. Management routines influencing piglet survival in loose-housed sow herds. Livest. Sci. 196, 1–6.

Rutherford, K.M.D., Baxter, E.M., D'Eath, R.B., Turner, S.P., Arnott, G., Roehe, R., Ask, B., Sandøe, P., Moustsen, V.A., Thorup, F., Edwards, S.A., Berg, P., Lawrence, A.B., 2013. The welfare implications of large litter size in the domestic pig I: biological factors. Anim. Welf. 22, 199–218. Available from: http://dx.doi.org/10.7120/09627286.22.2.199.

Sambraus, H.H., Baier, S., 2000. The reaction of sows to the weaning of the piglets. Tierärztliche Umschau. 55, 332–338.

Schmid, H., 1994. Ethological design of a practicable farrowing pen. Appl. Anim. Behav. Sci. 40, 94–95. Available from: http://dx.doi.org/10.1016/0168-1591(94)90124-4.

Schoenherr, W.D., Stahly, T.S., Cromwell, G.L., 1989. The effects of dietary fat or fiber addition on yield and composition of milk from sows housed in a warm or hot environment. J. Anim. Sci. 67, 482–495.

Serenius, T., Stalder, K.J., 2004. Genetics of length of productive life and lifetime prolificacy in the Finnish Landrace and Large White pig populations. J. Anim. Sci. 82, 3111–3117.

Sorensen, D., Vernersen, A., Andersen, S., 2000. Bayesian analysis of response to selection: a case study using litter size in Danish Yorkshire pigs. Genetics. 156, 283.

Spinka, M., Illmann, G., de Jonge, F., Andersson, M., Schuurman, T., Jensen, P., 2000. Dimensions of maternal behaviour characteristics in domestic and wild x domestic crossbred sows. Appl. Anim. Behav. Sci. 70, 99–114.

Stolba, A., Wood-Gush, D.G.M., 1984. The identification of behavioural key features and their incorporation into a housing design for pigs. Annales De Recherches Veterinaires. 15, 287–299.

Sørensen, J.T., Rousing, T., Kudahl, A.B., Hansted, H.J., Pedersen, L.J., 2016. Do nurse sows and foster litters have impaired animal welfare? Results from a cross-sectional study in sow herds. Animal. 10, 681–686.

Tallet, C., Brajon, C., Devillers, N., Lensink, J., 2017. Pig–human interactions: creating a positive perception of humans to ensure pig welfare. In: Špinka, M. (Ed.), Advances in Pig Welfare. Woodhead Publishing, Duxford, UK.

Thorup, F., 2007. Effect of a sow having functioned as a nurse sow. Report number 793, Dansk Svineproduktion bulletins. <http://www.danishpigproduction.dk/Research/Research_report/Reproduction.html>.

Trivers, R., 1972. Parental Investment and Sexual Selection. Sexual Selection & the Descent of Man. Aldine de Gruyter, New York, pp. 136–179.

Turner, S.P., Camerlink, I., Baxter, E.M., D'Eath, R.B., Desire, S., Roehe, R., 2017. Breeding for pig welfare; opportunities and challenges. In: Špinka, M. (Ed.), Advances in Pig Welfare. Woodhead Publishing, Duxford, UK.

van Nieuwamerongen, S.E., Bolhuis, J.E., Van Der Peet-Schwering, C.M.C., Soede, N.M., 2014. A review of sow and piglet behaviour and performance in group housing systems for lactating sows. Animal. 8, 448–460.

van Nieuwamerongen, S.E., Soede, N.M., van der Peet-Schwering, C.M.C., Kemp, B., Bolhuis, J.E., 2015. Development of piglets raised in a new multi-litter housing system vs. conventional single-litter housing until 9 weeks of age. J. Anim. Sci. 93, 5442–5454.

Vestergaard, E.M., Danielsen, V., 1998. Dietary fibre for sows: effects of large amounts of soluble and insoluble fibres in the pregnancy period on the performance of sows during three reproductive cycles. Anim. Sci. 67, 355–362.

Vestergaard, K., Hansen, L.L., 1984. Tethered versus loose sows: ethological observations and measures of productivity. I. Ethological observations during pregnancy and farrowing. Ann. Rech. Vet. 15, 245–256.

Waiblinger, S., Boivin, X., Pedersen, V., Tosi, M.V., Janczak, A.M., Visser, E.K., Jones, R. B., et al., 2006. Assessing the human–animal relationship in farmed species: a critical review. Appl. Anim. Behav. Sci. 101, 185–242.

Weary, D.M., Phillips, P.A., Pajor, E.A., Fraser, D., Thompson, B.K., 1998. Crushing of piglets by sows: effects of litter features, pen features and sow behaviour. Appl. Anim. Behav. Sci. 61, 103–111.

Weary, D.M., Pajor, E.A., Bonenfant, M., Fraser, D., Kramer, D.L., 2002. Alternative housing for sows and litters: Part 4. Effects of sow-controlled housing combined with a communal piglet area on pre-and post-weaning behaviour and performance. Appl. Anim. Behav. Sci. 76, 279–290.

Webb, A.J., 1998. Objectives and strategies in pig improvement: an applied perspective. J. Dairy. Sci. 81, 36–46.

Weber, R., 2000. Alternative housing systems for farrowing and lactating sows. In: Blokhuis, H.J., Ekkel, E.D., Wechsler, B. (Eds.), Improving Health and Welfare in Animal Production EAAP. Wageningen Pers, The Hague, The Netherlands, pp. 109–115.

Weber, R., Keil, N.M., Fehr, M., Horat, R., 2007. Piglet mortality on farms using farrowing systems with or without crates. Anim. Welf. 16, 277–279.

Weber, R., Keil, N.M., Fehr, M., Horat, R., 2009. Factors affecting piglet mortality in loose farrowing systems on commercial farms. Livestock Science. 124 (1), 216–222.

Welfare of Farmed Animals (England) Regulations, 2007. Home page. <http://www.legislation.gov.uk/>.

Welp, C., Jöchle, W., Holtz, W., 1984. Induction of parturition in swine with a prostaglandin analog and oxytoxin: a trial involving dose of oxytocin and parity. Theriogenology. 22, 509–520.

Whittemore, C.T., 1994. Causes and consequences of change in the mature size of the domestic pig. Outlook. Agric. 23, 55–59.

Wiepkema, P.R., 1986. Remarks on the behaviour of wild boar. Appl. Anim. Behav. Sci. 15, 179–180.

Williams, G.C., 1966. Natural selection, the costs of reproduction, and a refinement of Lack's principle. Am. Nat. 100, 687–690.

Wischner, D., Kemper, N., Stamer, E., Hellbruegge, B., Presuhn, U., Krieter, J., 2009. Characterisation of sows' postures and posture changes with regard to crushing piglets. Appl. Anim. Behav. Sci. 119, 49–55. Available from: http://dx.doi.org/10.1016/j.applanim.2009.03.002.

Yun, J., Swan, K.-M., Vienola, K., Farmer, C., Oliviero, C., Peltoniemi, O., Valros, A., et al., 2013. Nest-building in sows: effects of farrowing housing on hormonal modulation of maternal characteristics. Appl. Anim. Behav. Sci. 148, 77–84. Available from: http://dx.doi.org/10.1016/j.applanim.2013.07.010.

Yun, J., Swan, K.-M., Oliviero, C., Peltoniemi, O., Valros, A., 2015. Effects of prepartum housing environment on abnormal behaviour, the farrowing process, and interactions with circulating oxytocin in sows. Appl. Anim. Behav. Sci. 162, 20–25. Available from: http://dx.doi.org/10.1016/j.applanim.2014.11.006.

Zanella, A.J., Zanella, E.L., 1993. Nesting material used by free-range sows in Brazil. In: Nichelmann, M., Wierenga, H.K., & Braun, S. (Eds.), Proceedings of the Third Joint Meeting of the International Congress on Applied Ethology, Berlin. KTBL, Darmstadt, Germany, p. 411.

Piglet mortality and morbidity: inevitable or unacceptable?

3

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3.1 Introduction

Piglet mortality continues to be a major economic and welfare concern. Despite advances in knowledge to improve piglet survival, there have been no significant improvements in practice over the last 30 years, with total mortality (i.e., stillborn and live-born deaths) per litter averaging between 16% and 20%. Although the multifactorial nature of piglet mortality means single causal factors are difficult to identify, the recent focus on genetic selection strategies to increase litter size, and the concomitant negative impacts on survival, is a likely contributing factor hindering any substantial advances. These super-prolific breeding programmes are likely to persist, as it is unlikely that the financial pressures on pig farmers to produce high sow output in order to remain competitive will be alleviated. However, there is an increasing societal focus on the ethical and welfare issues in pig production. The welfare issue not only lies with piglets, who may suffer as a result of the nature of the different causes of death, but also with the sow because of restrictive housing conditions imposed to improve piglet survival. Improving piglet survival in an environment allowing adequate expression of sow behavioural needs, whilst challenging, meets both economic and societal goals and must therefore be a subject of intensive future research and development.

3.1.1 Current international levels and trends – are we making relative progress?

Trends over the last decade show fluctuations in pre-weaning mortality levels indicative of transient success. However, in most countries no downward trend is apparent (Fig. 3.1). The spike in pre-weaning mortality reported in the 2014 figures in the United States (Fig. 3.1) is most likely a result of the spread of porcine epidemic diarrhoea (PED) virus in 2013, which was reported to be responsible for the deaths of 8 million newborn piglets (Lee, 2015). In 2010, the Danish reports show that pre-weaning mortality started to reduce, even as litter size continued to increase. This coincided with a change in reporting method of national data (SEGES, 2015) which might explain this change in trend. However, there could be more likely explanations resulting from genetic and managerial

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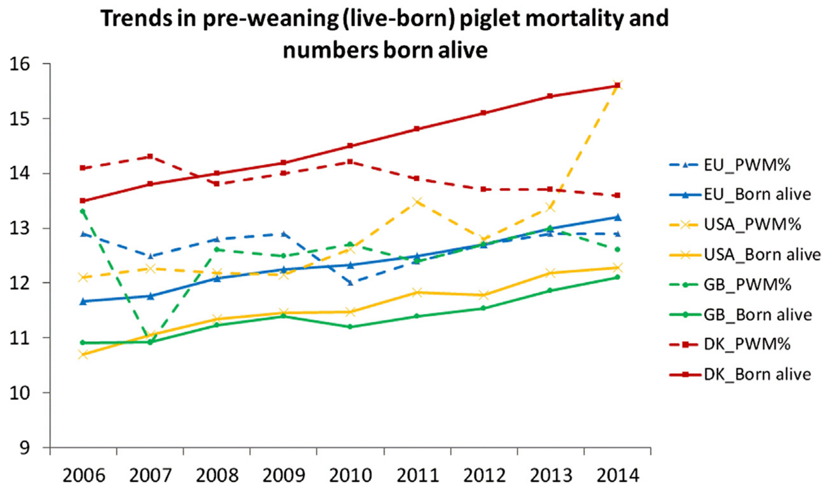

Figure 3.1 Trends in average pre-weaning mortality (PWM) and born alive in selected countries. *Source*: Data provided by Agricultural and Horticultural Development Board (AHDB) Pork's Interpig reports, PIGCHAMP and SEGES (2015).

improvements. For example, the downward trend could reflect changes made to genetic selection programmes to increase the weighting of piglet survival traits in breeding indices and the subsequent filtering through from nucleus herds to the wider population (Nielsen et al., 2013). It could also reflect the changes to the management strategies implemented on Danish farms to manage surplus piglets and thus improve survival. These interventions include use of nurse sows to rear piglets that would otherwise die (Baxter et al., 2017 Chapter 2: Sow welfare in the farrowing crate and alternatives.).

3.1.2 Economic, environmental and ethical importance

This chapter will concentrate on the welfare aspects of piglet mortality. However piglet mortality also represents a significant waste of resources and therefore is of economic and environmental importance. By keeping more piglets alive per litter, production efficiency will be improved by increasing the number of slaughter animals produced per sow, and thus reducing the overhead cost of maintaining the sow which must be carried by every kilogram (kg) of pig meat consumed. Fig. 3.2 shows the linear relationship between costs of production (euro/kg carcass) and pre-weaning piglet mortality. If piglet survival can be improved by as little as 0.5% this could increase annual pig meat output per sow by 10 kg, thus improving financial gains and reducing the environmental impact (per kg of product) of pork production as fewer sows will be needed to produce the same amount of meat. However, this may impose additional metabolic burden and welfare challenge for sows (Baxter et al., Chapter 2: Sow welfare in the farrowing crate and alternatives.).

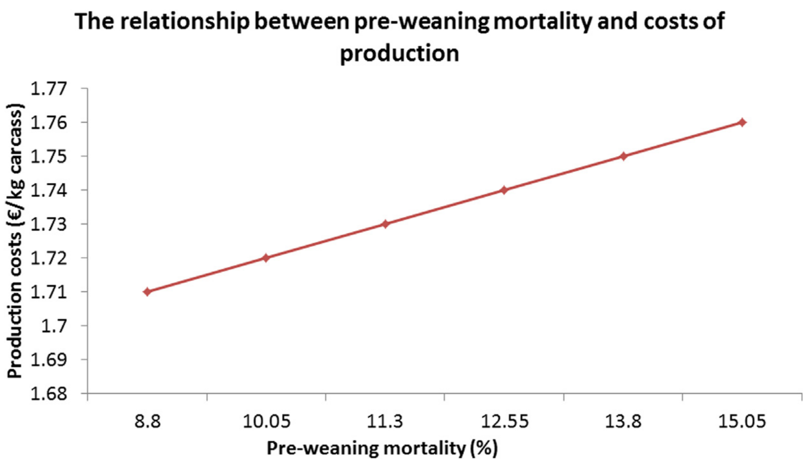

Figure 3.2 Relationship between pre-weaning piglet mortality (%) and the costs of production (Edwards and Baxter, 2012).

Enhancing efficiency in this way appears to satisfy a number of sustainability goals for livestock production. However, whilst reducing piglet mortality involves multiple 'wins' for different stakeholders, achieving increased sow output by increasing litter size at birth, with its associated negative impacts, introduces ethical conflicts. Whilst the economic and environmental aspects of sow productivity are important issues for all those involved in the supply chain, there is an increasing societal focus on the welfare aspects. For example, in 2010 the Danish Animal Protection Society highlighted the issue of high levels of piglet mortality, calculating that the relatively high level of piglet mortality in Denmark equated to nine million dead piglets per year. They concluded that: *the main proportion of piglets that die after birth are likely to be exposed to serious suffering in terms of either pain, hunger, fear or stress lasting from a few minutes up to 12 hours... The high proportion of dead piglets is therefore an ethical as well as a welfare problem, since most of the piglets that die after birth apparently die suffering* (Pedersen et al., 2010). They then went on to challenge the practice of breeding for higher litter size on welfare and ethical grounds, and also questioned whether the negative outcomes effectively rendered the practice illegal (for a more thorough discussion see Rutherford et al., 2011). Livestock production has historically exploited the natural biology of the animal to improve productivity (Merks, 2000). The question of whether the goal of ever-increasing litter size has resulted in modern intensive pig production straying beyond practices that are acceptable to the public is of high current importance.

3.1.3 The evolutionary aspects of piglet mortality – are we pushing it too far?

Perhaps a certain amount of piglet mortality is a predisposed and inevitable event. A percentage of piglets have always been expected to die before weaning (10%–20% per annum; Edwards, 2002) and conceivably this is a form of natural selection implemented by the sow whereby only the fittest will survive. This results from a form of parental optimism whereby the sow overproduces offspring at birth, thus allowing insurance offspring in the event of good rearing conditions whilst making little investment in piglets which might die early if conditions are unfavourable (Mock and Forbes, 1995; Forbes and Mock, 1998; Mock and Parker, 1998). It is important that any offspring superfluous to resources die quickly, with minimal compromise to the surviving littermates, and so the evolutionary strategy involves unequal provision of resources (i.e., milk) by the mother to her litter, resulting in intense sibling rivalry and early mortality of weaker individuals. This deposition of an over-supply of neonates into a spatially restrictive 'nursery' with a limited supply of resources commonly results in a form of siblicide (Mock and Parker, 1998). Authors have already suggested that, in swine, the competitive situation occurring after birth promotes selfishness that can be compared to that of avian facultative siblicide (Fraser et al., 1995; Edwards, 2002). The piglet's advanced dentition at birth, in the form of sharp needle teeth, arms it with weaponry that can be used to full effect against littermates when defending a teat. This territorial behaviour may be an evolutionary adaptation, intensified as a consequence of subsequent selection for increased litter size, where the piglets are claiming a productive and consistent milk source and securing their needs in the parent–offspring conflict (Puppe and Tuchscherer, 1999). When considering the prenatal environment with respect to these evolutionary strategies which promote siblicide (i.e., an over-supply of offspring and limited resources), it could be argued that sibling selfishness is evident long before birth. The over-supply by the sow is clear with high ovulation rates, again exacerbated by selection for prolificacy during domestication. In a study in domestic pigs, mummified piglets were found in 162 out of 192 litters (van der Lende and van Rens, 2003), whereas in wild boar Servanty et al. (2007) recorded only 5 such cases among 483 wild boar females. The uterus has a finite capacity and the competitive acquisition of adequate uterine space for individual placental development is essential for blood flow and delivery of nutrients vital for sustaining life. Several studies looking at embryonic survival have indicated that, prior to and during conceptus elongation, conceptuses can alter the uterine environment by secreting oestrogen (Anderson, 1978; Geisert et al., 1991; Pope, 1994). As a result of asynchronous elongation, some conceptuses will be more advanced than others and the more developed ones release estradiol 17β (E2β), creating a potentially hostile uterine environment for their less developed littermates, which impedes their elongation and results in degeneration. In a polytocous species, such as the pig, the capacity for parental optimism, individual embryo mortality and 'siblicide' are dependent on absolute litter size. Attempting to reduce piglet mortality under domestic conditions has had limited success and a major contributor to this is likely to be these hard-wired evolutionary strategies. Thus exploiting biology (i.e., selecting for high litter sizes) means battling against it (i.e., the associated mortality).

3.2 Mortality and welfare

3.2.1 Is mortality a welfare issue?

Is death a welfare issue? The side you support within this debate depends on whether you believe that depriving the animal of the future possibility to experience positive states by continuing life is a welfare issue. This question has been the subject of much debate and a full discussion is out of the scope of this chapter (for notable reviews on both sides see Webster, 1994; Yeates, 2010). There is a general consensus that death itself, whilst it may be of ethical concern, is not a welfare issue because if an animal ceases to exist it cannot experience pain, disease, suffering, etc. However, the events leading up to death (i.e., dying itself) can have welfare issues as there is potential to experience all of these negative states. Asphyxiation, starvation, hypothermia and physical trauma may be the fate of the newborn and it is highly likely that combinations of these will be experienced, as they are not mutually exclusive (Edwards, 2002). If the welfare issue relates to pain and suffering, another debate arises about when an animal is sufficiently aware to experience these negative states, and this discussion is particularly pertinent when we consider the birth process and the newborn animal.

3.2.2 Prevalence of different causes and their welfare implications

The majority of pre-weaning mortality occurs in the perinatal period, during the farrowing process and in the first few hours post-farrowing. Stillbirths typically account for 8% of total mortality (Leenhouwers et al., 1999). Among live-born piglets, more than half of the deaths occur within the first 3 days post-partum (English and Morrison, 1984; Marchant et al., 2000). This neonatal period is when the piglet is considered to be at its most vulnerable. English and Morrison (1984) classified the deaths of live-born piglets into: starvation and crushing (70%–80%), disease (6%) and congenital abnormalities (5%).

3.2.3 Stillbirths

Stillbirths are generally divided into two types; type one are antepartum deaths occurring before parturition and whose main aetiology has historically been thought to be intra-uterine infection, but now may increasingly be uterine crowding. When these occur sometime before parturition, degeneration of the foetus is apparent and they are often referred to as 'mummies'. The gestational age at which death occurred can be estimated by the size of the mummified foetus (Ullrey, 1965). A recent investigation showed a large range in age, with 90% of the mummies dying between 45 and 108 days of gestation (Pandolfi et al., 2017). Deaths occurring in the first half of gestation are unlikely to constitute a welfare issue, as the lack of neural development of the foetus would preclude sensibility (Mellor and Diesch, 2006). However, later type one deaths require further consideration, as do the type two stillbirths which are intrapartum deaths that occur just before expulsion is initiated, during expulsion or just after being born (Alonso-Spilsbury et al., 2005). The predisposing risk factors associated with this stillborn mortality are prolonged duration of farrowing, delivery in the last third of the birth order, premature rupture of the umbilical cord, sow behavioural (e.g., fearfulness, Hemsworth et al., 1999) and physiological characteristics, including higher parity and blood haemoglobin concentration of less than 9 g/100 mL (Randall, 1972a,b; Fahmy and Friend, 1981; Zaleski and Hacker, 1993; van Rens and van der Lende, 2004; van Djik et al., 2005; Baxter et al., 2008). These factors often result in fatal hypoxia (van der Lende et al., 2001; Alonso-Spilsbury et al., 2005; Mota-Rojas et al., 2005; van Dijk et al., 2008), or a less viable piglet with poor survival chances post-partum. Sow placental characteristics, which are reflected in piglet size and shape, influence prenatal survival. Piglets born with reduced physiological maturity (i.e., suffering from intra-uterine growth retardation/restriction, IUGR) are more likely to be born dead (Baxter et al., 2008; Hales et al., 2013; Amdi et al., 2013a).

What are the welfare implications of being born dead? If death is not a welfare issue it could be argued that stillbirth raises no problem for the piglet concerned. However this assumes a lack of awareness in the piglet at the point of death, and therefore the question of when animals develop awareness should be considered in relation to stillbirth and early postnatal death in piglets. Animals are widely accepted as being sentient and thus can experience both poor and good welfare states (Dawkins, 1990). Both sentience and consciousness are considered prerequisites of suffering (Mellor and Diesch, 2006), therefore it can be postulated that if a piglet is to suffer during morbidity and mortality it needs to be suitably aware. Mellor (2010), using data from foetal lamb electroencephalograms (EEG), has proposed that the foetus never properly gains consciousness until after birth. He categorises animals on the basis of their stage of neurological maturity at birth and, on this basis, extrapolation of his conclusions to piglets can be justified. The mechanisms by which consciousness is suppressed in utero have been reviewed in detail by Mellor et al. (2005). This has been attributed to the combined neuro-inhibitory actions of adenosine, a powerful EEG suppressor and sleep-inducing agent, allopregnanolone and pregnanolone, two neurosteroids which have anaesthetic, sedative and analgesic actions, and prostaglandin D2, a potent sleep-inducing hormone, supported by physical elements of the uterine environment, which are warmth, buoyancy and cushioning. As hypoxia increases the depth of adenosine-induced unconsciousness, any hypoxaemia induced by the parturition process will only further suppress awareness and piglets that die during this process should experience no suffering. Consciousness is only attained after birth when successful breathing oxygenates the blood and removes the adenosine suppression of cortical activity. This change, accompanied by other activators including oestradiol, noradrenaline and the multiple sensory inputs (especially mechanical and thermal) that are associated with birth, triggers the onset of the ability of the piglet to perceive negative stimuli (Mellor and Diesch, 2006).

3.2.4 Hypoxia, low viability/prematurity, hypothermia – do they have lesser pain perception?

Whilst most surveys attribute crushing as the predominant cause of postnatal piglet mortality, more detailed study of the aetiology of death shows that this is often predisposed by other events in the early life of the piglet. The hypothermia–starvation–crushing mortality complex is often initiated by postnatal hypoxia and low vitality (Edwards and Baxter, 2015), and hypothermia has long been considered, directly or indirectly, to be responsible as a primary cause for more deaths than crushing, starvation, disease or low viability (Curtis, 1970; Herpin et al., 2002). The neonatal piglet is the most cold-sensitive ungulate (Herpin and Le Dividich, 1995), born with very little adipose tissue and no brown fat (Herpin et al., 2002). This vulnerability has been exacerbated by genetic selection strategies focusing on lean meat (Herpin et al., 1993) and super-prolific breeding programmes lowering the average birth weight of a newborn (Rutherford et al., 2013). The piglet's capacity to produce heat is crucial to its survival and is dependent on the coordinated expression of various organs and processes. Hypothermia is the ultimate result of excessive heat loss due to a cold environment or depressed heat production ability (Herpin and Le Dividich, 1995).

Although adenosine suppression of cortical function declines very rapidly after birth, as a result of oxygenation of the tissues, it is possible that the neuro-inhibitory effects of some other gestational agents may carry over into the early postnatal period and influence the capacity of the newborn to perceive pain. In the newborn lamb, circulating concentrations of pregnanolone are still significant 3 days after birth (Nguyen et al., 2003) and increasing magnitude of response of the cerebral cortex to the noxious stimulation of castration can be seen over the first 7–10 days of postnatal life (Johnson et al., 2009). This change in the responsiveness of the cerebral cortex to noxious stimulation may be indicative of a change in the degree to which this is perceived consciously. Whilst no comparable EEG data are yet available for the piglet, this suggests the possibility that the suffering associated with some forms of very early life mortality may be reduced. The behavioural evidence is still ambiguous, with comparisons of pain vocalisations and behaviour in response to piglet tail docking at 1 or 3 days of age giving conflicting results (Torrey et al., 2009; Bovey et al., 2014). For further discussion of this issue see Herskin and Di Giminiani (Chapter 11: Pain in pigs: Characterisation, mechanisms and indicators).

Piglets that are hypoxic at birth, either as a result of chronic intra-uterine oxygen deprivation resulting from placental insufficiency or from more acute oxygen restriction as a result of cord compression or placental detachment during a prolonged farrowing, have elevated blood lactate and reduced vitality (English et al., 1975; Pedersen et al., 2011). Because of the hypoxic inhibition of postnatal heat production (Herpin et al., 2001), such piglets are also at greater risk of hypothermia, and can enter a downward spiral of lethargy, chilling, starvation and death. The risks are even greater for piglets that have experienced IUGR, as their lower birth weight and changed body conformation increase their surface area: volume ratio and hence rate of heat loss (Baxter et al., 2008). Low viability piglets that fail to suckle can show a reduction in body temperature of 4–5°C within the first 30 minutes of life (Pattison et al., 1990). Hypothermia of this magnitude is likely to be accompanied by a significant depression in cerebral function; cerebral metabolic rate and blood flow decline by 40%–50% when the core temperature decreases by 4–5°C (Busija and Leffler, 1987). Starved newborn piglets also exhibit hypoglycaemia-induced hypothermia and coma before death (Morrill, 1952). These facts, together with human experience that cognitive depression increases as hypothermia becomes gradually more severe, and this is not experienced as painful, suggests that low viability piglets that die of hypothermia before suckling may also experience relatively little suffering (Mellor and Stafford, 2004).

3.2.5 Crushing, savaging – mortality vs morbidity

Crushing is thought to account for the majority of neonatal deaths and, given its importance, it is a well-researched and documented area of the hypothermia–starvation–crushing mortality complex; crushing is often the ultimate cause of death with the proximate causes of hypothermia and starvation less easily identified. Fraser (1990) aptly likened the nature of a newborn piglet's situation to that of a human trapped in a small room with a large, erratic elephant. The newborn domestic piglet enters the extra-uterine environment with little or no fat reserve, immature physiological capacities, and an innate need to get to the udder of an animal often more than 250 times its size, who is potentially aggressive and unpredictable in her movements. It must do this in limited space and, depending on its birth order, must compete with numerous other newborns experiencing the same situation. Piglets prefer to lie close to the sow's udder during the first 24 h of life in order to establish and maintain ownership of a teat, as well as benefit from the sow as a radiant heat source. However they trade these benefits off against the risk of being crushed by the sow. Weary et al. (1996a) concluded that crushings are at least partly the result of the nutritional challenge facing piglets. They found that a piglet with slow weight gain spent more time in risky areas underneath its sitting or standing mother. If the piglet's energy reserves are low, it will also be too weak to escape a moving sow. The extent to which a piglet suffers pain at the point of crushing is somewhat dependant on whether or not it is also in a state of hypoxia, hypothermia and/or hypoglycaemia as discussed above. An aspect not covered as yet is whether or not the piglet experiences fear as a result of its mother's behaviour, either before or during a crush incident.

There has also been work on the type of sow body movements that crush piglets (Weary et al., 1996b), with conflicting results depending on farrowing system. Weary et al. (1996b) suggested that the rolling behaviour of sows crushed the most piglets in a loose-housed system, with sitting to lying transitions being the most risky in farrowing crates. Increased sitting behaviour in crated animals is thought to be a facet of the environment. The sows cannot control their interaction with the piglets as much as loose-housed sows can. In more natural systems, contact between piglets and the sow is controlled by the sow. In the first few days the sow will only leave the nest site periodically, but this gradually increases throughout the lactation period and weaning is considered a well-developed process long before the sow is finally removed in commercial outdoor environments (Wallenbeck et al., 2008). In the crates they cannot do this, therefore to 'escape' the demands of the piglets, sows in crates sit up more and increase the risk of sit-to-lie crushing. Some crush-types are likely to result in non-fatal injuries; for example in loose-housed environments wounds such as crushed toes or pierced stomachs, caused by sows stepping or kicking their piglets whilst walking around the pen, are reported as being non-fatal (Baxter et al., 2015) but with obvious welfare consequences, especially if they go untreated. A piglet clamped between the sow and a wall may not die from such a crush, but may spend a prolonged period of time in a state of distress.

The sow can be a contributor in reducing family size, not only through physical accidents, but also through intentional behaviour. The occurrence of savaging is well reported in pigs (e.g., Ahlstrom et al., 2002; Chen et al., 2008). It is a form of piglet-directed aggression which is more prevalent in primiparous animals (Jarvis et al., 2001; Harris et al., 2003; Vangen et al., 2005; Chen et al., 2008) and is thought to be linked to neophobia, as well as to an interaction between stress hormones and the farrowing environment (Lawrence et al., 1994; McLean et al., 1998; Jarvis et al., 1998). This interaction is discussed in more detail in Baxter et al. (Baxter et al., Chapter 2: Sow welfare in the farrowing crate and alternatives). Ahlstrom et al. (2002) found that savaging gilts were more restless and more responsive towards their piglets during farrowing and hypothesised that this was not necessarily a consequence of poor maternal ability, but more a result of the inability to adapt to the restrictive environment. Ison et al. (2015) observations of savaging gilts in crates and loose-housed pens further expands this argument. Although they observed piglet-directed aggression in both populations of gilts (bites, snaps and mouthing), they found the intensity of piglet-directed aggression was reduced much sooner in gilts housed loose compared with crated. The authors suggested the gilts who were loose had the ability to adapt to the novelty of the situation and develop a less negative mother–offspring relationship. Thus, when discussing these forms of piglet mortality, we highlight the welfare issues for the sow as well as the piglet.

With both crushing and savaging there is potential for the piglet to experience a prolonged period of morbidity. Both forms of mis-mothering can inflict non-fatal wounds. Crushing can be the ultimate end to a prior period of hypothermia and starvation and the disruptive behaviour associated with savaging may actually exacerbate hypothermia, starvation and crushing. Unless the piglet is already far down the hypoxia–hypothermia–hypoglycaemia spiral, or is killed instantaneously as a result of severe trauma, it is likely to experience significant pain and suffering before finally dying. These forms of mortality are consequently of major welfare concern.

3.2.6 Congenital abnormality, starvation, infection/disease – chronic states

Whilst low viability newborn piglets which fail to suckle may suffer relatively little because of the hypoglycaemia-induced hypothermia and coma which ensues relatively rapidly, the same cannot be said for more viable piglets that lose out in the competition for limited teat availability or are impaired by physical deformity such as splay legs (Falkenberg et al., 1991). Extreme hunger is known to give rise to pain and suffering, whilst failure to achieve adequate early colostrum intake will also predispose piglets to later infectious disease. Neonatal diseases have been described as entities resulting from the interaction of a multitude of factors (Martineau et al., 1995). The neonate is born with no immune protection because of the inability of immunoglobulin to cross the porcine placenta. If piglets fail to take in an adequate amount of colostrum soon after birth, there will be a suboptimal transfer of maternal immunoglobulins to the neonate. The period during which the gut is permeable to these large molecules is of limited duration and, by 24–48 h depending on time of first suckling, gut closure has taken place (Gaskins and Kelley, 1995; Rooke and Bland, 2002). The piglet's vigour and behaviour are important determinants in acquiring colostrum. Getting to the udder, acquiring a functional teat and suckling colostrum quickly not only aids thermoregulation and the acquisition of immunoglobulins and nutrients, but also initiates gut closure. There are two major windows of opportunity for pathogens to enter the piglet's systemic circulation. The first is within the first 24 h of life and is influenced by delayed colostrum intake which can cause subsequent delay in gut closure. The second opportunity is between the time of declining antibody levels in the sow's milk and the transition from passive to active immunity in the piglet over the first few weeks of life (Gaskins and Kelley, 1995). Poor management practice with regard to hygiene and lack of early treatment of infection will be major determinants of the risk of neonatal diseases and infections becoming fatal. Injuries acquired by the piglets are often the result of over-lying or savaging by the mother and, if they are not immediately fatal, they may result in infection and a prolonged death. It is also possible for the piglets to sustain wounds from the teeth of their siblings, or leg and foot abrasions from rough flooring, during the competitive scrambling for a teat at milk letdown (Brown et al., 1996; Furniss et al., 1986). Common farming practice is to teeth-clip the piglets soon after birth to remove the tips of the sharp needle teeth. This decreases the damage the piglets do to each other and to the sow's udder, but can also be a source of infection entry if the gum is damaged during this process (Sutherland, 2015).

Infectious disease is another mortality cause with serious welfare implications. Sleep and drowsiness, which are often observed during sickness, may mitigate suffering, but sickness is likely to give rise to a high level of negative affect (Weary et al., 2009). Some infections, such as those affecting the joints, result in clear behavioural signs of pain and can persist for extended periods of time. Rapid and appropriate treatment and, when necessary, humane euthanasia, is therefore essential.

3.2.7 Ethics of euthanasia

Given that the potential for suffering is great, if an animal is suffering then death is not detrimental to welfare as long as the method of death is considered humane. In fact it could be considered morally reprehensible not to euthanase an animal that is experiencing pain and suffering. The ethics of euthanasia may differ in different cultures and has become an increasingly discussed matter with great relevance to this chapter. Of specific debate is the blunt trauma method stockworkers commonly use to euthanase piglets and the social acceptability of such a method. The OIE define ‘humane killing’ as ‘killing by using a method that causes rapid and irreversible loss of consciousness with minimum pain and distress to the animal’ (OIE, 2011). The blunt force trauma method of euthanasing piglets is widely thought to achieve this objective; however the aesthetics of such a method have led to calls for renewed research efforts to find a humane and publically acceptable alternative. Inhalant gas euthanasia using chambers filled with carbon dioxide or nitrous oxide have been the subject of recent research. The former has raised serious welfare concerns, with significant aversive responses seen in piglets (Raj and Gregory, 1995; Rault et al., 2013), yet it is now being widely used to accommodate the need for an alternative. The latter has been shown to be far less aversive for piglets, as an apparent state of anaesthesia precedes death (Rault et al., 2015), yet uptake of this as an alternative will no doubt involve discussions about the relative cost and potential human safety issues. Thus, whilst euthanasia literally means ‘good death’, it is apparent that achieving such a state is a continuing challenge.

3.3 Mortality patterns and trends

3.3.1 Interactions between causes

As has been discussed in the previous section, few causes of mortality occur in isolation. Each cause is inextricably linked with other causes, either because they directly lead one to another or have common predisposing factors. Edwards and Baxter (2015) have illustrated these inter-dependencies in diagrammatic form. Fig. 3.3 shows a modified version to this in which the welfare implications have been included.

3.3.2 Different farms show different patterns

Whilst piglet mortality is often considered as a unitary problem, and benchmarks usually present only stillborn and live-born mortality, it is apparent that the problem can take very different forms on different farms. This was illustrated in a recent study of French farms experiencing problems of piglet mortality, in which standard procedures were used for post mortem examination of all dead piglets to determine the true cause of mortality (Pandolfi et al., 2017). This is important in epidemiological studies, because it has been frequently reported that farmer diagnoses may misclassify causes of death (Vaillancourt et al., 1990; Vanderhaeghe et al., 2009; Westin et al., 2015). Use of a cluster analysis showed that the French farms fell into three different groupings on the basis of their patterns of mortality. The first cluster grouped farms with a higher neonatal mortality rate due to crushing and starvation, but also acute diseases and dehydration or enteritis. All these categories

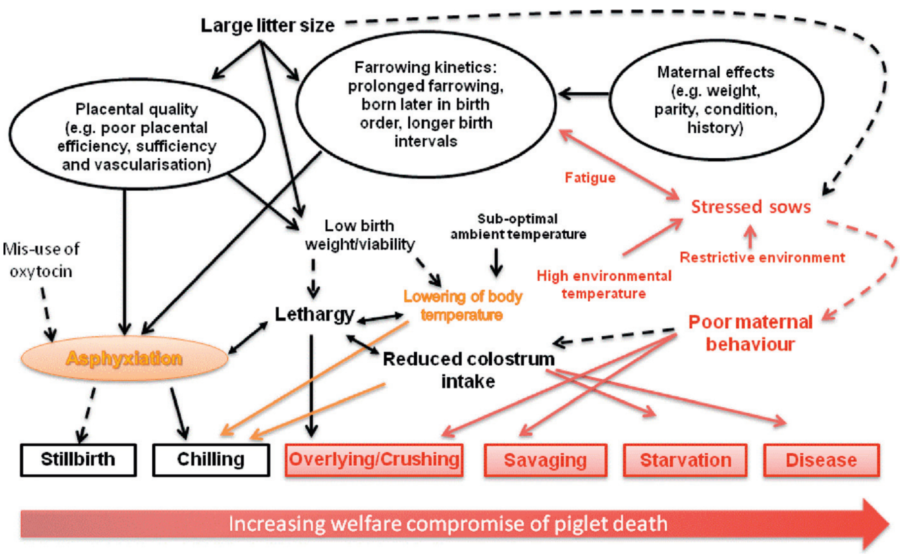

Figure 3.3 Predisposing risk factors of piglet mortality and welfare compromise. Factors in boxes are the direct causes of piglet death. Factors circled are individual or grouped indirect causes. Where red font and red shading have been used, evidence for a welfare compromise for either the sow or piglets is available. Where orange coloured font is used, the risk of a welfare compromise is dependent on the stage at which the animal is experiencing the risk factor.
Source: Adapted from Edwards and Baxter, 2015.

appear after piglet birth, and some of these categories showed intercorrelations, supporting the idea of a common process which impairs the viability, thermoregulation and susceptibility to infections of the piglets. The second cluster grouped farms with a high rate of death during farrowing and in utero sepsis. As the prevalence of death during farrowing was particularly high in this group, farrowing management practice might be an issue. The third cluster grouped farms with low piglet weight at death, due to a high prevalence of mummified and non-viable piglets. The average litter size in this cluster was also higher, suggesting an underlying intra-uterine crowding effect. Such studies have the potential to lead to more targeted management strategies to reduce neonatal mortality on individual farms.

3.3.3 Consequences of industry changes – prolificacy, free farrowing

The trends over time which were illustrated in Section 3.1 (Fig. 3.1) reflect the challenges faced by the industry in achieving future reductions in piglet mortality.

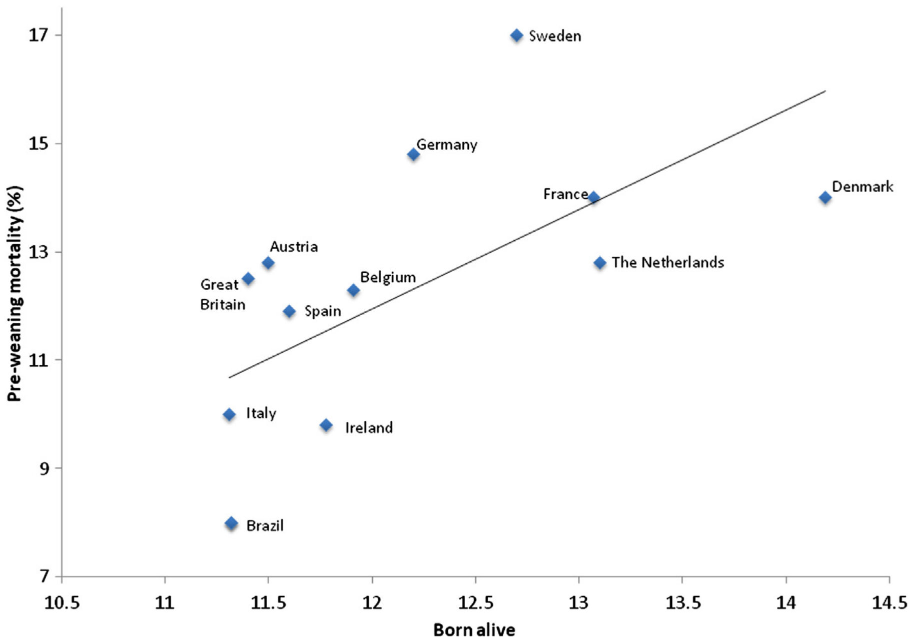

Figure 3.4 Relationship between litter size and piglet mortality in selected countries. *Source*: Data to produce figure taken from Interpig (2009). AHDB Pork 2009. Interpig report. Pig cost of production in selected countries. Agriculture and Horticulture Development Board (AHDB) Pork, Stoneleigh, UK.

Fig. 3.4 shows the relationship between litter size and piglet mortality for different European countries and highlights two important issues. The first, already alluded to many times, is that of prolificacy. In countries such as Denmark, France and The Netherlands, where high total litter sizes are now common as a result of genetic selection for prolificacy, the level of piglet mortality has also increased in percentage terms and therefore even more so in terms of absolute numbers of individual animals. The link between litter size and mortality can be influenced by a more balanced selection policy, incorporating survival traits as well as litter size traits in the breeding index and assigning appropriate weightings to each (Su et al., 2007; Nielsen et al., 2013). It can also be influenced by changed management practices on the farm to provide additional support for supernumerary piglets, but this demands a high level of both time and skill to be successful. Both these strategies could be influencing current figures in Denmark showing improvements in survival (Fig. 3.1). The second issue illustrated by Fig. 3.4 is that of the farrowing system. Sweden has relatively higher mortality in relation to its litter size, and this has been suggested to result from the farrowing crate ban which was enacted nationally many years ago. In many countries there is now increasing societal pressure to find alternatives to the farrowing crate, which is deemed to compromise sow welfare through both physical and behavioural restriction (Baxter et al., Chapter 2: Sow welfare in the farrowing crate and alternatives). Comparative studies show that many free-farrowing systems have yielded higher mortality than conventional crate systems (Baxter et al., 2012), and this is particularly the case when such systems move to a less controlled commercial environment. However, in some situations it has been possible to achieve comparable survival in free-farrowing systems (Weber et al., 2007; Edwards et al., 2011; Baxter et al., 2012), and a new generation of designed pens is showing promise for a way forward.

3.4 Interventions to reduce mortality and their implications

Piglet mortality can be addressed through changes in genetic selection strategies of the animals, alterations in the farrowing environment, or changes in management. As the challenges of hyperprolificacy increase, all of these measures need to be optimised.

3.4.1 Genetic selection – piglet vitality, maternal behaviour, udder quality

Adjusting selection criteria to include neonatal survival, in addition to number born, is a more sustainable strategy than simply selecting solely for a larger litter size to offset high incidences of piglet mortality. Whilst the heritability of piglet survival is generally low (h^2 of ~0.1 or less), use of advanced statistical tools in genetic selection within large breeding populations allows significant progress to be made. The Danish pig industry, renowned for its success in increasing litter size, has recognised the accompanying significant increase in mortality which occurred (5% increase in total pre-weaning mortality). In 2004 it changed its selection criterion from 'total born' to 'live piglets at day 5' (LP5) (Su et al., 2007) and, although mortality is still high, this has been stabilised with the net result of an increase of 2.3 pigs weaned/litter. This may reflect successful management of the surplus piglets, or indicate that selecting for survival may not result in as many compromised piglets (e.g., pathologically growth retarded) as selecting for number born. Selecting directly for reduced mortality has also been demonstrated to successfully influence survival rates, with a reduction of mortality of 3% over a 2-generation breeding intervention experiment in outdoor sows (Roehe et al., 2009, 2010). Reducing intra-litter variability, particularly with respect to birth weight, is an additional important breeding goal discussed by numerous authors (Rydhmer, 2000; Knol et al., 2002a,b; Damgaard et al., 2003). Selecting for improved placental efficiency is another potential strategy to improve piglet outcomes (van Rens et al., 2005). Furthermore, breeding for improved maternal behaviour (Grandison, 2005; Gade et al., 2007; Baxter et al., 2011a) and investigating strategies for breeding a more robust piglet both have potential to improve survival. More recently, attention has focused on the possibilities for genetic improvement of udder conformation and colostrum quality to aid the rapid ingestion of an adequate amount of colostral energy and immunoglobulin (Balzani et al., 2016a). These traits have been shown to have moderate heritability (h^2 of 0.2–0.3) and therefore to be feasible targets for genetic progress (Balzani et al., 2016b).

3.4.2 Environmental selection – especially pen design and heat

Early research to reduce piglet mortality was centred almost entirely around alterations to the farrowing environment. Increased control over the macro- and microclimate of the birth site and nest area (e.g., Morrison et al., 1983) and, of course, the introduction of the farrowing crate (Robertson et al., 1966) are some examples of tools put in place to improve piglet survival. Whilst the farrowing crate has given significant benefits for piglet survival (Edwards and Fraser, 1997), it imposes physical restrictions that impact on sow welfare, preventing the fulfilment of important species-specific behaviours such as nest-building (see Baxter et al., Chapter 2: Sow welfare in the farrowing crate and alternatives, for a full discussion of the role of housing in the determination of good maternal behaviour which will benefit piglet survival).

The importance of designing facilities to minimise hypothermia at birth was illustrated in the early experiments of Morrison et al. (1983). Use of supplementary radiant heating at the birth site and adjacent to the udder, where piglets spend the early hours of postnatal life, markedly improved piglet survival. Even when a heated creep area is provided, piglets often take an extended time to locate and consistently use this area (Vasdal et al., 2010) and piglets of marginal viability may not survive this period. New technologies are developing more effective types of radiant heater for the purpose of reducing hypothermia in the immediate post-partum period and these are likely to be of great value in aiding the establishment of hypoxic and low birth weight individuals (Pedersen et al., 2016). Such provision is easy in a farrowing crate system that fixes the sow's location, but is more challenging in a loose farrowing pen where the birth site cannot be reliably predicted. In loose pens, a significant reduction in mortality was demonstrated with the use of under-floor heating in the nest area during the first 24 h after farrowing (Malmkvist et al., 2006). Another alternative, exploited very effectively by outdoor producers, is to use the drying, insulating and cushioning properties of straw bedding. The provision of plentiful bedding during farrowing and the first days of life has been shown to significantly reduce mortality in loose farrowing pens (Westin et al., 2015).

The other perceived advantage of the farrowing crate for piglet survival lies in the physical protection from crushing that it can provide by restricting the movement and rate of posture change of the sow, allowing piglets more time to escape when the sow lies down or rolls over. Where loose farrowing pens are used, the incorporation of piglet protection features, such as sloped walls to assist controlled lying by the sow and facilitate piglet escape, are therefore critical features for success. The design of new farrowing systems, and adjustments to existing systems, should consider options that build on understanding pig behaviour in order to optimise both sow and piglet welfare (see review of Baxter et al., 2011b).

3.4.3 Management – nutrition, supervision, intervention, fostering, nurse sows

3.4.3.1 Nutritional interventions

Given the importance of birth weight as a survival indicator, nutritional interventions have focused on ways to improve embryo quality and subsequent birth weight and uniformity, including use of fermentable ingredients in sow diets prior to breeding (Van den Brand et al., 2009), and essential amino acids at the time of placental development (Wu et al., 2004). More recently, efforts have been focused on how best to deal with the increasing population of IUGR piglets; Amdi et al. (2013b) found that piglets born with severe IUGR had less brain sparing if their mothers were fed palm acid distillate, whilst essential fatty acid supplementation in late gestation can increase piglet vitality (Rooke et al., 2001; Bontempo and Jiang, 2015). Campos et al. (2012) published a recent review on these offspring benefits, whilst Meunier-Salaün et al. (2001) and De Leeuw et al. (2008) discussed the influence of nutritional interventions on sow welfare.

Preparing the peri-parturient sow for the exhaustive process of parturition and lactation is an important component of ensuring piglet survival, as well as good sow health and welfare. Given the impact that super-prolific breeding programmes are having on the length of farrowing, it is even more important to mitigate uterine and maternal fatigue. For the modern hyperprolific sow, parturition is a marathon event; it is not uncommon for sows carrying large litters to have farrowings lasting 9 h (Hales et al., 2015), where 4–5 h was previously classified as a long farrowing (Oliviero et al., 2010). Longer farrowing duration increases the risk of both maternal and uterine fatigue leading to stillbirth or a live-born piglet compromised by hypoxia (Alonso-Spilsbury et al., 2005). Feeding during the transitioning process of late gestation to lactation may play a role in the farrowing process. Including fibre in the diet prior to parturition may have several benefits comprising alleviation of constipation (Oliviero et al., 2010) and greater and prolonged uptake of energy from the gastrointestinal tract (see Theil, 2015 for review). Hepatic and muscle glycogen are the main piglet body stores imparting heat-producing nutrients for oxidation. In the newborn piglet these can be depleted within 12–17 h of birth in the absence of colostrum ingestion (Theil et al., 2011). In addition to increasing core body temperature, colostrum ingestion is important for both energy balance and immune protection. Piglets will have access to colostrum continuously for approximately 12 h from the start of farrowing before cyclical letdown of milk occurs every 20 min. Immature organ development will impact upon the piglet's ability to process any milk it obtains and there is a finite amount of time before gut closure commences (approximately 48 h) when it is important for the piglet to obtain and process colostrum (Cranwell, 1995). Getting to the udder, commanding a functional teat and suckling colostrum quickly not only aids thermoregulation and the acquisition of immunoglobulins and nutrients, but also aids gut closure. Lactational output of the sow is a vital aspect of determining how much colostrum the piglets receive. A variety of dietary interventions can affect the composition of colostrum and therefore piglet survival. For example, high fibre gestation diets (Quesnel et al., 2015) and dietary fat inclusion late in gestation may improve colostrum yield (Hansen et al., 2012) and increase total lipid and lactose content in colostrum, as well as colostral IGF-1 concentration (Farmer and Quesnel, 2009). Bontempo et al. (2004) demonstrated that dietary conjugated linoleic acid affected fatty acid composition and positively affected immunologic variables in colostrum, and could be transferred to the offspring via the dam during suckling (Bee, 2000).

3.4.4 Optimising management

3.4.4.1 Prenatal management

Optimising management during gestation to limit the social and nutritional stressors experienced by the sow and her developing offspring is an important aspect of reducing piglet mortality. Maternal stress during gestation can lead to higher pre-weaning mortality of live-born piglets. This may be as a result of a barren group housing system giving rise to elevated cortisol in the dam (Merlot et al., 2016) or partly related to human behaviour and pig fear levels interacting to influence piglet mortality by influencing maternal behaviour and impairing piglet colostrum uptake (as assessed through immunoglobulin levels) (Tuchscherer et al., 2002). Poor management of pregnant sows that increases stress levels, particularly at the stage in gestation when the foetal hypothalamic pituitary axis is developing, can have long-term effects on piglet stress reactivity which can impair immune function, health, behaviour and future reproductive success, including future mothering ability. Given the challenges already faced by neonatal piglets, increased stress reactivity as a result of prenatal programming will be a further detriment. Limiting stress during pregnancy will reduce the risk of negative prenatal programming. In addition, positive handling of sows for short daily periods prior to farrowing can reduce fearfulness (Andersen et al., 2006), with potential benefits for maternal behaviour and thus piglet survival.

3.4.4.2 Farrowing

Supervision at the time of parturition, and obstetric intervention in the case of prolonged inter-birth intervals, can substantially reduce the incidence of stillbirths (English and Edwards, 1996), whilst extra care of weak piglets immediately after birth can reduce postnatal mortality (see Kirkden et al., 2013a for a review). In countries that employ high labour input in the farrowing house, piglet mortality levels are relatively low (e.g., Brazil, Fig. 3.4), suggesting that with the correct managerial inputs mortality is not a foregone conclusion (if the piglet is not pathologically compromised). To optimise human inputs, pharmacological induction of parturition is sometimes used to synchronise farrowings and facilitate supervision and interventions which may reduce piglet mortality (Černe and Jöchle, 1981). However, this can also be counterproductive if done incorrectly because of increased birthing complications and stillbirths (Mota-Rojas et al., 2002). The timing of induction is critical, as late foetal development and maturation is a predisposing factor for survival (Randall, 1972a,b; van der Lende et al., 2001). In the days preceding farrowing, the foetus experiences an increase in growth rate (Biensen et al., 1998) and development, with final physiological preparations for extra-uterine life, particularly lung maturation. Premature induction of birth may therefore result in a compromised neonate. The general consensus is not to induce parturition before Day 113 of gestation (see Kirkden et al., 2013b for review) and to avoid this intervention in gilts, as service dates are often inaccurate. Administration of oxytocin is another pharmacological intervention designed to aid the farrowing progress in situations of fatigue. However, if used inappropriately this can increase foetal asphyxia by strengthening the uterine muscle contractions, impeding gaseous exchange between mother and foetus, and increasing the chances of umbilical occlusion (Alonso-Spilsbury et al., 2004, 2005; Mota-Rojas et al., 2002, 2006). Administration of oxytocin in these studies resulted in increased piglet bradycardia and meconium staining, with severe acidosis and compromised survival. Thus the misuse of drugs is an important risk factor in piglet mortality.

3.4.4.3 Post-partum management: colostrum intake and fostering

Piglets must ingest colostrum as soon as possible after birth. A major factor in successfully being able to achieve this is the behaviour of the mother. If the sow is calm during farrowing, adopting a lateral lying posture and exposing her udder, piglets will have safe passage to suckle colostrum. Reducing stress in the peri-parturient sow will help achieve this desired somnolent state and improve farrowing progression. Ensuring appropriate sow condition, minimising heat stress and providing enrichment to allow nest-building behaviour and reduce frustration (Thodberg et al., 1999; Jarvis et al., 2001, 2002; Damm et al., 2003, 2005) are all important management factors. Providing substrate will not only facilitate improved maternal behaviour (Herskin et al., 1998), but will also provide a microclimate for newborn piglets.

Even if maternal behaviour and physiology are optimised, additional interventions are necessary when litter size exceeds functional teat number and when there is a greater number of low vitality, growth-retarded piglets (Baxter et al., 2013). Targeted inputs by stockpeople can assist piglets with their landmark behaviours to get to the udder quickly and suck colostrum. Further diligence would involve oral supplementation of colostrum, which can be particularly effective for low birth weight piglets. Muns et al. (2014) demonstrated that providing an oral supplementation of sow colostrum to piglets weighing less than 1.35 kg within 4 h of birth increased IgG levels at Day 4 post-partum. When surplus piglets are routinely being produced, other managerial interventions must be applied, including split suckling and cross-fostering to achieve litter equalisation or standardisation (i.e., similar size piglets). If performed correctly, cross-fostering enhances piglet survival (English et al., 1977; Cecchinato et al., 2008) and can reduce the need for further management interventions for piglets that would otherwise suffer from remaining in a large litter, or those low birth weight piglets that are failing to compete for a productive teat with their larger littermates. However, there are different welfare concerns associated with some fostering practices. These concerns relate to the time after birth when fostering occurs and the problems with over-fostering (Baxter et al., 2013). Some farm managers will repeatedly cross-foster piglets, moving them from sow to sow in an attempt to achieve more even weaning weights. However, such practices are very disruptive for both the sow and piglets and thus counterproductive, with continuously cross-fostered piglets failing to suckle regularly, acquiring facial lacerations and showing no improvement in weaning weights (Robert and Martineau, 2001).

In countries like Denmark, where super-prolific breeding programmes have resulted in consistent production of surplus piglets, the use of nurse sows (i.e., foster mothers) is now close to ubiquitous. However, such strategies have yet to be widely used in other countries. They require diligent stockpersonship and there are risks to the health and welfare of both piglets and sows (Baxter et al., 2013), particularly if performed poorly. Artificial rearing systems are now widely used in The Netherlands, the United States and increasingly in Germany, to deal with surplus piglets. For example, the Rescue Deck system is a specially designed unit that is recommended to sit above the farrowing crates and houses either surplus or low viability piglets. Scientific evidence regarding the advantages and disadvantages of artificial rearing systems in terms of welfare and the long-term survival prospects of 'rescued' piglets is sparse and, if such practices are to be adopted, they require further investigation.

Although optimum birth weight is considered key to survival and piglets being born under such an optimum have poor lifetime prospects, more recent evidence suggests that for piglets born under 1.8 kg in weight, it is their weaning weight that can predict their lifetime performance as measured by growth potential (Douglas et al., 2014). It is thought such piglets have the capacity to demonstrate catch-up growth if provided with the correct resources. Therefore ensuring high milk intake during the pre-weaning period for smaller piglets may help them to reach their growth potential. Supplementary milk provision in the farrowing environment, in addition to a stable suckling environment, will aid this endeavour. However this work only refers to the growth potential of these piglets. Determining lifetime health and welfare prospects of piglets which are suboptimal at birth requires evaluation using further measurements in addition to growth.

3.5 Conclusions and future trends

The incidence of piglet mortality is multifaceted in nature and, as a result, finding solutions must address all aspects of the problem. When considering the welfare implications for the piglet, least concern relates to those piglets that never develop full and rhythmic breathing and hence never gain full consciousness (i.e., those that die during labour or immediately after). A medium level of concern attaches to piglets that develop full breathing but descend quickly into hypothermia (and hence reduced awareness) over the immediate hours following birth, whilst high concern focuses around piglets that develop full breathing, are not hypothermic, but suffer slow deaths from hunger, injury or disease as they will have developed full consciousness and hence potential to suffer.

The export of super-prolific breeding stock by international breeding companies suggests the trends and challenges associated with large litter sizes are set to continue, which could equate to absolute values of piglet mortality increasing. However, if management is optimised as detailed above, there is potential to wean more piglets. The quality of those piglets must be ensured; it should not be enough to just survive; to experience a good life, piglets should be thriving. However, the trade-off for sow welfare to promote piglet survival is already great, and in the quest to improve piglet survival there should not be further restrictions placed on the sow. Given the associations between large litter sizes and piglet mortality, and the concomitant sow welfare concerns of large litters, is it ethical to continue these trends? If management can be optimised and sow welfare can be improved, how much mortality is then acceptable?

Abbreviations

EEG electroencephalograms
IUGR intra-uterine growth retardation

References

AHDB Pork, 2006–2016. Interpig Reports. Pig Cost of Production in Selected Countries. Agriculture and Horticulture Development Board (AHDB) Pork, Stoneleigh, UK.

Ahlström, S., Jarvis, S., Lawrence, A.B., 2002. Savaging gilts are more restless and more responsive to piglets during the expulsive phase of parturition. Appl. Anim. Behav. Sci. 76 (1), 83–91.

Alonso-Spilsbury, M., Mota-Rojas, D., Villanueva-García, D., Martínez-Burnes, J., Orozco, H., Ramírez-Necoechea, R., Mayagoitia, A.L., Trujillo, M.E., 2005. Perinatal asphyxia pathophysiology in pig and human: a review. Anim. Reprod. Sci. 90 (1–2), 1–30.

Alonso-Spilsbury, M., Mota-Rojas, D., Martínez-Burnes, J., Arch, E., Lopez Mayagoitia, A., Ramírez-Necoechea, R., et al., 2004. Use of oxytocin in penned sows and its effect on fetalintra-partum asphyxia. Anim. Reprod. Sci. 84 (1–2), 157–167. Available from: http://dx.doi.org/10.1016/j.anireprosci.2003.11.002.

Amdi, C., Hansen, C.F., Krogh, U., Oksbjerg, N., Theil, P.K., (2013a). Less brain sparing occurs in severe intrauterine growth-restricted piglets born to sows fed palm fatty acid distillate. In: Manipulating Pig Production XIV. APSA Biennial Conference, Melbourne, Victoria, Australia, 24–27 November, p. 125.

Amdi, C., Krogh, U., Flummer, C., Oksbjerg, N., Hansen, C.F., Theil, P.K., 2013b. Intrauterine growth restricted piglets defined by their head shape ingest insufficient amounts of colostrum. J. Anim. Sci. 91, 5605–5613.

Andersen, I.L., Berg, S., Bøe, K.E., Edwards, S., 2006. Positive handling in late pregnancy and the consequences for maternal behaviour and production in sows. Appl. Anim. Behav. Sci. 99 (1–2), 64–76.

Anderson, L.L., 1978. Growth, protein content and distribution of early pig embryos. Anat. Rec. 190, 143–154.

Balzani, A., Cordell, H.J., Edwards, S.A., 2016a. Relationship of sow udder morphology with piglet suckling behaviour and teat access. Theriogenology. 86, 1913–1920.

Balzani, A., Cordell, H.J., Sutcliffe, E., Edwards, S.A., 2016b. Heritability of udder morphology and colostrum quality traits in swine. J. Anim. Sci. 94, 3636−3644.
Baxter, E.M., Adeleye, O.O., Jack, M.C., Farish, M., Ison, S.H., Edwards, S.A., 2015. Achieving optimum performance in a loose-housed farrowing system for sows: the effects of space and temperature. Appl. Anim. Behav. Sci. 169, 9−16.
Baxter, E.M., Jarvis, S., D'Eath, R.B., Ross, D.W., Robson, S.K., Farish, M., Nevison, I.M., Lawrence, A.B., Edwards, S.A., 2008. Investigating the behavioural and physiological indicators of neonatal survival in pigs. Theriogenology. 69, 773−783.
Baxter, E.M., Jarvis, S., Sherwood, L., Farish, M., Roehe, R., Lawrence, A.B., Edwards, S.A., 2011a. Genetic and environmental effects on piglet survival and maternal behaviour of the farrowing sow. Appl. Anim. Behav. Sci. 130 (1−2), 28−41.
Baxter, E.M., Lawrence, A.B., Edwards, S.A., 2011b. Alternative farrowing systems: design criteria for farrowing systems based on the biological needs of sows and piglets. Animal. 5, 580−600.
Baxter, E.M., Lawrence, A.B., Edwards, S.A., 2012. Alternative farrowing accommodation: welfare and economic aspects of existing farrowing and lactation systems for pigs. Animal. 6, 96−117.
Baxter, E.M., Rutherford, K.M.D., D'Eath, R.B., Arnott, G., Turner, S.P., Sandøe, P., Moustsen, V.A., Thorup, F., Edwards, S.A., Lawrence, A.B., 2013. The welfare implications of large litter size in the domestic pig II: management factors. Anim. Welfare. 22, 219−238.
Baxter, E.M., Andersen, L.I., Edwards, S.A., 2017. Sow welfare in the farrowing crate and alternatives? In: Špinka, M. (Ed.), Advances in Pig Welfare. Woodhead Publishing, Duxford, UK.
Bee, G., 2000. Dietary conjugated linoleic acid consumption during pregnancy and lactation influences growth and tissue composition in weaned pigs. J. Nutr. 130, 2981−2989.
Biensen, N.J., Wilson, M.E., Ford, S.P., 1998. The impact of either a Meishan or Yorkshire uterus on Meishan or Yorkshire fetal and placental development to days 70, 90, and 110 of gestation. J. Anim. Sci. 76, 2169−2176.
Bontempo, V., Jiang, X.R., 2015. Feeding various fat levels in sows: effects on immune status and performance of sows and piglets. In: Farmer, C. (Ed.), The Gestating and Lactating Sow. Academic Publishers, Wageningen, Netherlands, pp. 357−375.
Bontempo, V., Sciannimanico, D., Pastorelli, G., Rossi, R., Rosi, F., Corino, C., 2004. Dietary conjugated linoleic acid positively affects immunologic variables in lactating sows and piglets. J. Nutr. 134, 817−824.
Bovey, K.E., Widowski, T.M., Dewey, C.E., et al., 2014. The effect of birth weight and age at tail docking and ear notching on the behavioral and physiological responses of piglets. J. Anim. Sci. 92, 1718−1727.
Brown, J.M.E., Edwards, S.A., Smith, W.J., Thompson, E., Duncan, J., 1996. Welfare and production implications of teeth clipping and iron injection of piglets in outdoor systems in Scotland. Prev. Vet. Med. 27, 95−105.
Busija, D.W., Leffler, C.W., 1987. Hypothermia reduces cerebral metabolic rate and cerebral blood flow in newborn pigs. Am. J. Physiol. 253, H869−H873.
Campos, P.H.R.F., Silva, B.A.N., Donzele, J.L., Oliveira, R.F.M., Knol, E.F., 2012. Effects of sow nutrition during gestation on within-litter birth weight variation: areview. Animal. 6, 797−806.
Cecchinato, A., Bonfatti, V., Gallo, L., Carnier, P., 2008. Survival analysis of preweaning piglet survival in a dry-cured ham-producing crossbred line. J. Anim. Sci. 86, 2486−2495.

Cerne, F., Jochle, W., 1981. Clinical evaluations of a new prostaglandin analog in pigs: 1. Control of parturition and of the MMA-syndrome. Theriogenology. 16, 459–467.
Chen, C., Gilbert, C.L., Yang, G., Guo, Y., Segonds-Pichon, A., Ma, J., Evans, G., Brenig, B., Sargent, C., Affara, N., Huang, L., 2008. Maternal infanticide in sows: incidence and behavioural comparisons between savaging and non-savaging sows at parturition. Appl. Anim. Behav. Sci. 109 (2–4), 238–248.
Cranwell, P.D., 1995. Development of the neonatal gut. In: Varley, M.A. (Ed.), The Neonatal Pig: Development and Survival. CAB International, UK, pp. 99–154.
Curtis, S.E., 1970. Environmental-thermoregulatory interactions and neonatal piglet survival. J. Anim. Sci. 31, 576–587.
Damgaard, L.H., Rydhmer, L., Lovendahl, P., Grandinson, K., 2003. Genetic parameters for within-litter variation in piglet birth weight and change in within-litter variation during suckling. J. Anim. Sci. 81, 604–610.
Damm, B.I., Pedersen, L.J., Heiskanen, T., Nielsen, N.P., 2005. Long-stemmed straw as an additional nesting material in modified Schmid pens in a commercial breeding unit: effects on sow behaviour, and on piglet mortality and growth. Appl. Anim. Behav. Sci. 92, 45–60.
Damm, B.I., Pedersen, L.J., Marchant-Forde, J.N., Gilbert, C.L., 2003. Does feed-back from a nest affect periparturient behaviour, heart rate and circulatory cortisol and oxytocin in gilts? Appl. Anim. Behav. Sci. 83, 55–76.
Dawkins, M.S., 1990. From an animal's point of view: motivation, fitness, and animal welfare. Behav. Brain Sci. 13, 1–61.
De Leeuw, J.A., Bolhuis, J.E., Bosch, G., Gerrits, W.J.J., 2008. Effects of dietary fibre on behaviour and satiety in pigs. Proc. Nutr. Soc. 67, 334.
Douglas, S.L., Edwards, S.A., Kyriazakis, I., 2014. Management strategies to improve the performance of low birth weight pigs to weaning and their long term consequences. J. Anim. Sci. 92, 2280–2288.
Edwards, S.A., 2002. Perinatal mortality in the pig: environmental or physiological solutions? Livest. Prod. Sci. 78, 3–12.
Edwards, S.A., Baxter, E.M., 2012. Producing 2 tonnes of pigs per sow. Keynote. Adv. Pork Prod. 23, 185–189. Proc of the 2012 Banff Pork Seminar, Banff, Canada, 17–20 January 2012.
Edwards, S.A., Baxter, E.M., 2015. Piglet mortality: causes and prevention. In: Farmer, C. (Ed.), The Gestating and Lactating Sow. Academic Publishers, Wageningen, Netherlands, pp. 253–269.
Edwards, S.A., Brett, M., Guy, J.H., Baxter, E.M., 2011. Practical evaluation of an indoor free farrowing system: the PigSAFE pen. In: 62nd Annual Meeting of the European Federation of Animal Science, Stavanger, Norway, p. 17.
Edwards, S.A., Fraser, D., 1997. Housing systems for farrowing and lactation. Pig J. 39, 77–89.
English, P.R., Edwards, S.A., 1996. Management of the nursing sow and her litter. In: Taverner, M.R., Dunkin, A.C. (Eds.), Pig Production: C10 (World Animal Science). Elsevier Health Sciences, Oxford, UK, pp. 113–140.
English, P.R., Morrison, V., 1984. Causes and prevention of piglet mortality. Pig News Inform. 5, 369–375.
English, P.R., Smith, W.J., 1975. Some causes of death in neonatal piglets. Vet. Ann. 15, 95–104.
English, P.R., Smith, W.J., MacLean, A., 1977. The Sow: Improving Her Efficiency. Farming Press Limited, Ipswich, UK.

Fahmy, M.H., Friend, D.W., 1981. Factors influencing, and repeatability of the duration of farrowing in Yorkshire sows. Can. J. Anim. Sci. 61, 17–22.
Falkenberg, H., Ritter, E., Zschorlich, B., 1991. Studies into the occurrence of genetic-defects in breeding pig-populations. Arch. Tierz. 34, 41–50.
Farmer, C., Quesnel, H., 2009. Nutritional, hormonal and environmental effects on colostrum in sows. J. Anim. Sci. 2009, 56–65.
Forbes, L.S., Mock, D.W., 1998. Parental optimism and progeny choice: when is screening for offspring quality affordable. J. Theor. Biol. 192, 3–14.
Fraser, D., 1990. Behavioural perspectives on piglet survival. J. Reprod. Fertil. Suppl. 40, 355–370.
Fraser, D., Kramer, D.L., Pajor, E.A., Weary, D.M., 1995. Conflict and cooperation: socio-biological principles and the behaviour of pigs. Appl. Anim. Behav. Sci. 44, 139–157.
Furniss, S.J., Edwards, S.A., Lightfoot, A.L., Spechter, H.H., 1986. The effect of floor type in farrowing pens on pig injury. I. Leg and teat damage of suckling piglets. Br. Vet. J. 434–440.
Gade, S., Bennewitz, J., Kirchner, K., Looft, H., Knap, P.W., Thaller, G., et al., 2007. Genetic parameters for maternal behaviour traits in sows. Livest. Sci. 114, 31–41.
Gaskins, H.R., Kelley, K.W., 1995. Immunology and neonatal mortality. In: Varley, M.A. (Ed.), The Neonatal Pig: Development and Survival. CAB International, Wallingford, UK, pp. 39–56.
Geisert, R.D., Morgan, G.L., Zavy, M.T., Blair, R.M., Gries, L.K., Cox, A., Yellin, T., 1991. Effect of asynchronous transfer and estrogen administration on survival and development of porcine embryos. J. Reprod. Fertil. 93, 475–481.
Grandinson, K., 2005. Genetic background of maternal behaviour and its relation to offspring survival. Livest. Prod. Sci. 93, 43–50.
Hales, J., Moustsen, V.A., Devreese, A.M., Nielsen, M.B.F., Hansen, C.F., 2015. Comparable farrowing progress in confined and loose housed hyper-prolific sows. Livest. Sci. 171, 64–72.
Hales, J., Moustsen, V.A., Nielsen, M.B.F., Hansen, C.F., 2013. Individual physical characteristics of neonatal piglets affect preweaning survival of piglets born in a noncrated system. J. Anim. Sci. 91, 4991–5003.
Hansen, A.V., Lauridsen, C., Sorensen, M.T., Knudsen, K.E.B., Theil, P.K., 2012. Effects of nutrient supply, plasma metabolites, and nutritional status of sows during transition on performance in the next lactation. J. Anim. Sci. 90, 466–480.
Harris, M.J., Li, Y.Z., Gonyou, H.W., 2003. Savaging behaviour in gilts and sows. Can. J. Anim. Sci. 83, 819–821.
Hemsworth, P.H., Pedersen, V., Cox, M., Cronin, G.M., Coleman, G.J., 1999. A note on the relationship between the behavioural response of lactating sows to humans and the survival of their piglets. Appl. Anim. Behav. Sci. 65, 43–52.
Herpin, P., Le Dividich, J., 1995. Thermoregulation and the environment. In: Varley, M.A. (Ed.), The Neonatal Pig: Development and Survival. CAB International, Wallingford, UK, pp. 57–95.
Herpin, P., Damon, M., Le Dividich, J., 2002. Development of thermoregulation and neonatal survival in pigs. Livest. Prod. Sci. 78, 25–45.
Herpin, P., Hulin, J.C., Le Dividich, J., Fillaut, M., 2001. Effect of oxygen inhalation at birth on the reduction of early postnatal mortality in pigs. J. Anim. Sci. 79, 5–10.
Herpin, P., Le Dividich, J., Amaral, N., 1993. Effect of selection for lean tissue-growth on body-composition and physiological-state of the pig at birth. J. Anim. Sci. 71, 2645–2653.

Herskin, M.S., Jensen, K.H., Thodberg, K., 1998. Influence of environmental stimuli on maternal behaviour related to bonding, reactivity and crushing of piglets in domestic sows. Appl. Anim. Behav. Sci. 58 (3–4), 241–254.

Herskin, M.S., Di Giminiani, P., 2017. Pain in pigs: characterisation, mechanisms and indicators. In: Špinka, M. (Ed.), Advances in Pig Welfare. Woodhead Publishing, Duxford, UK.

Ison, S.H., Wood, C.M., Baxter, E.M., 2015. Pre-pubertal gilt behaviour during human interaction and startle object tests and the relationship with farrowing in conventional crates or PigSAFE pens. Appl. Anim. Behav. Sci. 170, 26–33.

Jarvis, S., Calvert, S.K., Stevenson, J., vanLeeuwen, N., Lawrence, A.B., 2002. Pituitary-adrenal activation in pre-parturient pigs (*Sus scrofa*) is associated with behavioural restriction due to lack of space rather than nesting substrate. Anim. Welfare. 11, 371–384.

Jarvis, S., Lawrence, A.B., Mclean, K.A., Chirnside, J., Deans, L.A., Calvert, S.K., 1998. The effect of environment on plasma cortisol and beta-endorphin in the parturient pig and the involvement of endogenous opioids. Anim. Reprod. Sci. 52, 139–151.

Jarvis, S., Van der Vegt, B.J., Lawrence, A.B., McLean, K.A., Deans, L.A., Chirnside, J., Calvert, S.K., 2001. The effect of parity and environmental restriction on behavioural and physiological responses of pre-parturient pigs. Appl. Anim. Behav. Sci. 71, 203–216.

Johnson, C.B., Sylvester, S.P., Stafford, K.J., Mitchinson, S.L., Ward, R.N., Mellor, D.J., 2009. Effects of age on the electroencephalographic response to castration in lambs anaesthetized with halothane in oxygen from birth to 6 weeks old. Vet. Anaesth. Anal. 36, 273–279.

Kirkden, R.D., Broom, D.M., Andersen, I.L., 2013a. Invited review: piglet mortality: management solutions. J. Anim. Sci. 91, 3361–3389.

Kirkden, R.D., Broom, D.M., Andersen, I.L., 2013b. Piglet mortality: the impact of induction of farrowing using prostaglandins and oxytocin. Anim. Reprod. Sci. 138 (1–2), 14–24.

Knol, E.F., Ducro, B.J., van Arendonk, J.A.M., van der Lende, T., 2002a. Direct, maternal and nurse sow genetic effects on farrowing-, pre-weaning- and total piglet survival. Livest. Prod. Sci. 73, 153–164.

Knol, E.F., Leenhouwers, J.I., van der Lende, T., 2002b. Genetic aspects of piglet survival. Livest. Prod. Sci. 78, 47–55.

Lawrence, A.B., Petherick, J.C., McLean, K.A., Deans, L.A., Chirnside, J., Gaughan, A., Clutton, E., Terlouw, E.M.C., 1994. The effect of environment on behaviour, plasma cortisol and prolactin in parturient sows. Appl. Anim. Behav. Sci. 39 (3–4), 313–330.

Lee, C., 2015. Porcine epidemic diarrhea virus: an emerging and re-emerging epizootic swine virus. Virol. J. 12, 193.

Leenhouwers, J.I., van der Lende, T., Knol, E.F., 1999. Analysis of stillbirth in different lines of pig. Livest. Prod. Sci. 57, 243–253.

Malmkvist, J., Pedersen, L.J., Damgaard, B.M., Thodberg, K., Jørgensen, E., Labouriau, R., 2006. Does floor heating around parturition affect the vitality of piglets born to loose housed sows? Appl. Anim. Behav. Sci. 99, 88–105.

Marchant, J.N., Rudd, A.R., Mendl, M.T., Broom, D.M., Meredith, M.J., Corning, S., Simmins, P.H., 2000. Timing and causes of piglet mortality in alternative and conventional farrowing systems. Vet. Rec. 147, 209–214.

Martineau, G.P., Vaillancourt, J.P., Broes, A., 1995. Principal neonatal diseases. In: Varley, M.A. (Ed.), The Neonatal Pig Development and Survival. CAB International, UK, pp. 239–268.

McLean, K.A., Lawrence, A.B., Petherick, J.C., Deans, L., Chirnside, J., Vaughan, A., Nielsen, B.L., Webb, R., 1998. Investigation of the relationship between farrowing

environment, sex steroid concentrations and maternal aggression in gilts. Anim. Reprod. Sci. 50 (1–2), 95–109.
Mellor, D.J., 2010. Galloping colts, fetal feelings, and reassuring regulations: putting animal-welfare science into practice. J. Vet. Med. Educ. 37, 94–100.
Mellor, D.J., Diesch, T.J., 2006. Onset of sentience: the potential for suffering in fetal and newborn farm animals. Appl. Anim. Behav. Sci. 100, 48–57.
Mellor, D.J., Stafford, K.J., 2004. Animal welfare implications of neonatal mortality and morbidity in farm animals. Vet. J. 168, 118–133.
Mellor, D.J., Diesch, T.J., Gunn, A.J., Bennet, L., 2005. The importance of 'awareness' for understanding fetal pain. Brain Res. Rev. 49, 455–471.
Merks, J.W.M., 2000. One century of genetic changes in pigs and the future needs. In: Hill, W.G., Bishop, S.C., McGuirk, B., McKay, J.C., Simm, G., Webb, A.J. (Eds.), The Challenge of Genetic Change in Animal Production. British Society of Animal Science, Edinburgh, pp. 8–19.
Merlot, E., Calvar, C., Prunier, A., 2016. Influence of the housing environment during sow gestation on maternal health, and offspring immunity and survival. Anim. Prod. Sci. Available from: http://dx.doi.org/10.1071/AN15480.
Meunier-Salaun, M.C., Edwards, S.A., Robert, S., 2001. Effect of dietary fibre on the behaviour and health of the restricted fed sow. Anim. Feed Sci. Technol. 90, 53–69.
Mock, D.W., Forbes, L.S., 1995. The evolution of parental optimism. Trends Ecol. Evol. 10, 130–134.
Mock, D.W., Parker, G.A., 1998. Siblicide, family conflict and the evolutionary limits of selfishness. Anim. Behav. 56, 1–10.
Morrill, C.C., 1952. Studies on baby pig mortality. X. Influence of environmental temperature on fasting newborn pigs. Am. J. Vet. Res. 13, 322–324.
Morrison, V., English, P.R., Lodge, G.A., 1983. The effect of alternative creep heating arrangements at two house temperatures on piglet lying behaviour and mortality in the neonatal period. Anim. Prod. 36, 530–531.
Mota-Rojas, D., Martinez-Burnes, J., Trujillo-Ortega, M.E., Alonso-Spilsbury, M.L., Ramirez-Necoechea, R., Lopez, A., 2002. Effect of oxytocin treatment in sows on umbilical cord morphology, meconium staining, and neonatal mortality of piglets. Am. J. Vet. Res. 63, 1571–1574.
Mota-Rojas, D., Rosales, A.M., Trujillo, M.E., Orozco, H., Ramírez, R., Alonso-Spilsbury, M., 2005. The effects of vetrabutin chlorhydrate and oxytocin on stillbirth rate and asphyxia in swine. Theriogenology. 64, 1889–1897.
Mota-Rojas, D., Trujillo, M.E., Martínez, J., Rosales, A.M., Orozco, H., Ramírez, R., Sumano, H., Alonso-Spilsbury, M., 2006. Comparative routes of oxytocin administration in crated farrowing sows and its effects on fetal and postnatal asphyxia. Anim. Reprod. Sci. 92, 123–143.
Muns, R., Silva, C., Manteca, X., Gasa, J., 2014. Effect of cross-fostering and oral supplementation with colostrums on performance of newborn piglets. J. Anim. Sci. 92, 1193–1199.
Nguyen, P.N., Billiards, S.S., Walker, D.W., Hirst, J.J., 2003. Changes in 5alpha-pregnane steroids and neurosteroidogenic enzyme expression in the perinatal sheep. Pediatr. Res. 53, 956–964.
Nielsen, B., Su, G., Lund, M.S., Madsen, P., 2013. Selection for increased number of piglets at day five after farrowing has increased litter size and reduced piglet mortality. J. Anim. Sci. 91, 2575–2582.
OIE (World Organisation for Animal Health), 2011. Terrestrial animal health code. Available at: http://www.oie.int/doc/ged/D10905.PDF.

Oliviero, C., Heinonen, M., Valros, A., Peltoniemi, O., 2010. Environmental and sow-related factors affecting the duration of farrowing. Anim. Reprod. Sci. 119, 85–91.

Pandolfi, F., Edwards, S.A., Robert, F., Kyriazakis, I., 2017. Risk factors associated with the different categories of piglet perinatal mortality in French farms. Prevent. Vet. Med. 137, 1–12.

Pattison, P.J., English, P.R., McPherson, O., Roden, J.A., Birnie, M., 1990. Hypothermia and its control in newborn piglets. Proc. Br. Soc. Anim. Prod. 50 (3), 568.

Pedersen, L.J., Berg, P., Jørgensen, E., Bonde, M.K., Herskin, M.S., Møllegaard Knage-Rasmussen, K., Kongsted, A.G., Lauridsen, C., Oksbjerg, N., Poulsen, H.D., Sorensen, D.A., Su, G., Sørensen, M.T., Theil, P.K., Thodberg, K., Jensen, K.H., (2010). Pattegrisedødelighed i dk: Muligheder for reduktion af pattegrisedødeligheden i Danmark. DJF Rapport Husdyrbrug Nr. 86.

Pedersen, L.J., Berg, P., Jorgensen, G., Andersen, I.L., 2011. Neonatal piglet traits of importance for survival in crates and indoor pens. J. Anim. Sci. 89, 1207–1218.

Pedersen, L.J., Larsen, M.L.V., Malmkvist, J., 2016. The ability of different thermal aids to reduce hypothermia in neonatal piglets. J. Anim. Sci. 94, 2151–2159.

PigCHAMP. http://www.pigchamp.com/.

Pope, W.F., 1994. Embryonic mortality in swine. In: Geisert, R.D., Zavy, M.T. (Eds.), Embryonic Mortality in Domestic Species. CRC Press, Boca Raton, pp. 53–78.

Puppe, B., Tuchscherer, A., 1999. Developmental and territorial aspects of suckling behaviour in the domestic pig (*Sus scrofa* f. domestica). J. Zool. 249, 307–313.

Quesnel, H., Farmer, C., Theil, P.K., 2015. Colostrum and milk production. In: Farmer, C. (Ed.), The Gestating and Lactating Sow. Wageningen Academic Publisher, Wageningen, The Netherlands, pp. 173–192.

Raj, A., Gregory, M., 1995. Welfare implications of the gas stunning of pigs 1. Determination of aversion to the initial inhalation of carbon dioxide or argon. Anim. Welfare. 44, 273–280.

Randall, G., 1972a. pH values and blood-gas tensions in the normal piglet during the first 48h of life. Biol. Neonate. 20, 68–73.

Randall, G., 1972b. Observations on parturition in the sow. II. Factors influencing stillbirth and perinatal mortality. Vet. Rec. 90, 183–186.

Rault, J.-L., Kells, N., Johnson, C., Dennis, R., Sutherland, M., Lay Jr, D.C., 2015. Nitrous oxide as a humane method for piglet euthanasia: behavior and electroencephalography (EEG). Physiol. Behav. 151, 29–37.

Rault, J.-L., McMunn, K.A., Marchant-Forde, J.N., Lay Jr, D.C., 2013. Gas alternatives to carbon dioxide for euthanasia: a piglet perspective. J. Anim. Sci. 914, 1874–1883.

Robert, S., Martineau, G.P., 2001. Effects of repeated cross-fosterings on preweaning behavior and growth performance of piglets and on maternal behavior of sows. J. Anim. Sci. 79, 88–93.

Robertson, J.B., Laird, R., Forsyth, J.K.S., Thomson, J.M., Walker-Love, T., 1966. A comparison of two indoor farrowing systems for sows. Anim. Prod. 8, 71.

Roehe, R., Shrestha, N.P., Mekkawy, W., Baxter, E.M., Knap, P.W., Smurthwaite, K.M., Jarvis, S., Lawrence, A.B., Edwards, S.A., 2009. Genetic analyses of piglet survival and individual birth weight on first generation data of a selection experiment for piglet survival under outdoor conditions. Livest. Sci. 121 (2–3), 173–181.

Roehe, R., Shrestha, N.P., Mekkawy, W., Baxter, E.M., Knap, P.W., Smurthwaite, K.M., Jarvis, S., Lawrence, A.B., Edwards, S.A., 2010. Genetic parameters of piglet survival and birth weight from a two-generation crossbreeding experiment under outdoor conditions designed to disentangle direct and maternal effects. J. Anim. Sci. 88, 1276–1285.

Rooke, J.A., Bland, I.M., 2002. The acquisition of passive immunity in the new-born piglet. Livest. Prod. Sci. 78, 13–23.

Rooke, J.A., Sinclair, A.G., Edwards, S.A., Cordoba, R., Pkiyach, S., Penny, P.C., Penny, P., Finch, A.M., Horgan, G.W., 2001. The effect of feeding salmon oil to sows throughout pregnancy on pre-weaning mortality of piglets. Anim. Sci. 73, 489–500.

Rutherford, K.M.D., Baxter, E.M., Ask, B., Berg, P., D'Eath, R.B., Jarvis, S., Jensen, K.K., Lawrence, A.B., Moustsen, V.A., Robson, S.K., Roehe, R., Thorup, F., Turner, S.P., Sandoe, P., 2011. The ethical and welfare implications of large litter size in the domestic pig: challenges and solutions. Project Report 17, Danish Centre for Bioethics, Denmark and Risk Assessment and Scottish Agricultural College, UK.

Rutherford, K.M.D., Baxter, E.M., D'Eath, R.B., Turner, S.P., Arnott, G., Roehe, R., Ask, B., Sandøe, P., Moustsen, V.A., Thorup, F., Edwards, S.A., Berg, P., Lawrence, A.B., 2013. The welfare implications of large litter size in the domestic pig I: Biological factors. Anim. Welfare. 22, 199–218.

Rydhmer, L., 2000. Genetics of sow reproduction, including puberty, oestrus, pregnancy, farrowing and lactation. Livest. Prod. Sci. 66, 1–12.

SEGES, 2015. NOTAT NR. 1611. Landsgennemsnittet for produktivitet 2015 viser en fremgang på 0,8 fravænnet gris pr. årsso. Smågrisene viser en forbedring i foderudnyttelse på 0,05 FEsv pr. kg og slagtesvinene viser en forbedring i foderforbrug på 0,04 FEsv pr. kg tilvækst.

Servanty, S., Gaillard, J.-M., Allainé, D., Brandt, S., Baubet, E., 2007. Litter size and fetal sex ratio adjustment in a highly polytocous species: the wild boar. Behav. Ecol. 18, 427–432.

Su, G., Lund, M.S., Sorensen, D., 2007. Selection for litter size at day five to improve litter size at weaning and piglet survival rate. J. Anim. Sci. 85, 1385–1392.

Sutherland, M.A., 2015. Welfare implications of invasive piglet husbandry procedures, methods of alleviation and alternatives: a review. N. Z. Vet. J. 63, 52–57.

Theil, P.K., 2015. Transition feeding of sows. In: Farmer, C. (Ed.), The Gestating and Lactating Sow, 503 ed. Wageningen Academic Publishers, Wageningen, Netherlands, pp. 147–172.

Theil, P.K., Cordero, G., Henckel, P., Puggaard, L., Oksbjerg, N., Sorensen, M.T., 2011. Effects of gestation and transition diets, piglet birth weight, and fasting time on depletion of glycogen pools in liver and 3 muscles of newborn piglets. J. Anim. Sci. 89, 1805–1816.

Thodberg, K., Jensen, K.H., Herskin, M.S., Jørgensen, E., 1999. Influence of environmental stimuli on nest building and farrowing behaviour in domestic sows. Appl. Anim. Behav. Sci. 63, 131–144.

Torrey, S., Devillers, N., Lessard, M., Farmer, C., Widowski, T., 2009. Effect of age on the behavioral and physiological responses of piglets to tail docking and ear notching. J. Anim. Sci. 87, 1778–1786.

Tuchscherer, M., Kanitz, E., Otten, W., Tuchscherer, A., 2002. Effects of prenatal stress on cellular and humoral immune responses in neonatal pigs. Vet. Immunol. Immunopathol. 86, 195–203.

Ullrey, D.E., Sprague, J.L., Becker, D.E., Miller, E.R., 1965. Growth of the swine fetus. J. Anim. Sci. 24, 711–717.

Vaillancourt, J., Stein, T.E., Marsh, W.E., Leman, A.D., Dial, G.D., 1990. Validation of producer-recorded categories of preweaning mortality in swine. Prev. Vet. Med. 10, 119–130.

Van den Brand, H., van Enckevort, L.C.M., van der Hoeven, E.M., Kemp, B., 2009. Effects of dextrose plus lactose in the sows diet on subsequent reproductive performance and within litter birth weight variation. Reprod. Domest. Anim. 44, 884–888.

van der Lende, T., van Rens, B., 2003. Critical periods for foetal mortality in gilts identified by analysing the length distribution of mummified foetuses and frequency of non-fresh stillborn piglets. Anim. Reprod. Sci. 75, 141–150.

van der Lende, T., Knol, E.F., Leenhouwers, J.I., 2001. Prenatal development as a predisposing factor for perinatal losses in pigs. J. Reprod. Fertil. Suppl. 58, 247–261.

van Dijk, A.J., Jonker, F.H., Taverne, M.A.M., 2008. The effect of administration of 2-iminobiotin at birth on growth rates, morbidity and mortality in piglets under farm conditions. Livest. Sci. 115, 129–136.

van Dijk, A.J., van Rens, B.T.T.M., van der Lende, T., Taverne, M.A.M., 2005. Factors affecting duration of the expulsive stage of parturition and piglet birth intervals in sows with uncomplicated, spontaneous farrowings. Theriogenology. 64, 1573–1590.

van Rens, B.T., van der Lende, T., 2004. Parturition in gilts: duration of farrowing, birth intervals and placenta expulsion in relation to maternal, piglet and placental traits. Theriogenology. 62 (1–2), 331–352.

van Rens, B.T.T.M., de Koning, G., Bergsma, R., van der Lende, T., 2005. Preweaning piglet mortality in relation to placental efficiency. J. Anim. Sci. 83, 144–151.

Vanderhaeghe, C., Dewulf, J., De Vliegher, S., Papadopoulos, G.A., de Kruif, A., Maes, D., 2009. Longitudinal field study to assess sow level risk factors associated with stillborn piglets. Anim. Reprod. Sci. 120, 78–83.

Vangen, O., Holm, B., Valros, A., Lund, M.S., Rydhmer, L., 2005. Genetic variation in sows' maternal behaviour, recorded under field conditions. Livest. Prod. Sci. 93, 63–71.

Vasdal, G., Glærum, M., Melišová, M., BØe, K.E., Broom, D.M., Andersen, I.L., 2010. Increasing the piglets' use of the creep area – a battle against biology? Appl. Anim. Behav. Sci. 125, 96–102.

Wallenbeck, A., Rydhmer, L., Thodberg, K., 2008. Maternal behaviour and performance in first-parity outdoor sows. Livest. Sci. 116 (1), 216–222.

Weary, D.M., Huzzey, J.M., von Keyserlingk, M.A.G., 2009. Using behavior to predict and identify ill health in animals. J. Anim. Sci. 87, 770–777.

Weary, D.M., Pajor, E.A., Thompson, B.K., Fraser, D., 1996a. Risky behaviour by piglets: a trade off between feeding and risk of mortality by maternal crushing? Anim. Behav. 51, 619–624.

Weary, D.M., Pajor, E.A., Fraser, D., Honkanen, A.M., 1996b. Sow body movements that crush piglets: a comparison between two types of farrowing accommodation. Appl. Anim. Behav. Sci. 49, 149–158.

Weber, R., Keli, N., Fehr, M., Horat, R., 2007. Piglet mortality on farms using farrowing systems with or without crates. Anim. Welfare. 16, 277–279.

Webster, J., 1994. Animal Welfare: A Cool Eye Towards Eden. Blackwell Publishing, Oxford.

Westin, R., Hultgren, J., Algers, B., 2015. Strategic use of straw increases nest building in loose housed farrowing sows. Appl. Anim. Behav. Sci. 166, 63–70.

Wu, G., Bazer, F.W., Cudd, T.A., Meininger, C.J., Spencer, T.E., 2004. Maternal nutrition and fetal development. J. Nutr. 134, 2169–2172.

Yeates, J.W., 2010. Death is a welfare issue. J. Agric. Environ. Ethics. 23, 229–241.

Zaleski, H.M., Hacker, R.R., 1993. Comparison of viability scoring and blood gas analysis as measures of piglet viability. Can. J. Anim. Sci. 73, 649–653.

Lifetime consequences of the early physical and social environment of piglets

4

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4.1 Introduction

Most studies on pig behaviour and welfare have been carried out on pigs past the weaning age: sows, gilts and growing-finishing pigs. However, a growing body of evidence shows that young piglets also are substantially affected by their environment. In addition to effects on piglet behaviour and welfare at the time, the environment causes lifelong effects by modulating the development of behaviour, physiology and cognition (reviewed in Vanheukelom et al., 2012). In this chapter, the focus will be on the first weeks of a piglets' life, from birth to early post-weaning. The term environment will refer to any influences affecting a piglet from outside: physical factors such as available materials and space, social factors such as the presence of the mother and siblings, as well as interactions between physical and social factors. The main aim of this chapter is to present an overview of the current knowledge on lifelong effects of the early environment (for summary of the known main effects, shown to reduce see Fig. 4.1). Immediate impacts on piglet behaviour and welfare will also be summarised, and some new questions for future research will be highlighted.

4.1.1 *Long-term effects of early experiences in other species*

Early experiences have been found to modulate the development of behaviour and cognition in a number of species among mammals, birds and fish, suggesting such permanent effects may be ubiquitous among vertebrates. There are two different types of processes via which early environments cause lifelong consequences. One of them is phenotypic plasticity as part of normal development. Natural environments of most species vary in their amount of adversity, such as presence of predators or availability of food. For each environment, the set of optimal behavioural strategies is partly different. When young individuals develop in environments that differ in the amount and types of adversity, but this variation is within the limits for which the species is evolutionary adapted, those individuals develop partly different capabilities and profiles of learning, fearfulness, motivation for exploration, etc., in each case adaptively attuned to the specific environment in which the individual

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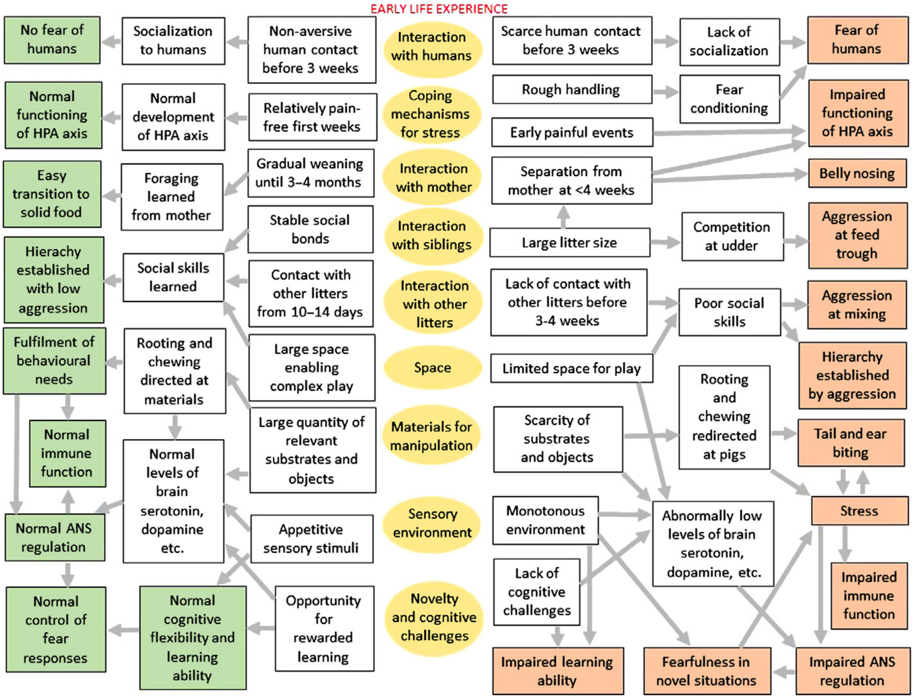

Figure 4.1 Illustration of the positive and negative consequences of different early life experiences of piglets.

lived in its early ontogeny. The second process involves abnormal early environments for which the species has not evolved appropriate developmental responses. The early ontogenetic environment can be severely disrupted or unnatural for the species in several ways, e.g., by subjecting the individual to traumatic events or lacking parts of the environmental input that is needed for normal behavioural and cognitive development. In such cases, the environment in early ontogeny results in individuals that are deficient in their coping abilities. Of these two processes, the second is the main topic of this chapter, as it is involved in the development of several behaviour and welfare problems that occur in the pig industry.

Some examples of findings in farm animals illustrating developmental consequences of whether the early environment provides the appropriate stimuli needed for social and cognitive development include cattle showing a better ability to cope with unfamiliar conspecifics if reared with conspecifics as calves (De Paula Vieira et al., 2012); sheep showing less fear towards humans if they have had positive experience of tactile interaction with humans in their early life (Boivin et al., 2000); chickens reared with added environmental complexity developing a better learning ability (Krause et al., 2006); and anxiety and injurious feather-pecking in chickens being reduced by early exposure to substrates or objects (reviewed in Janczak and Riber, 2015) as well as by maternal care (reviewed in Rodenburg, 2014). In farmed fish, a number of traits such as anxiety, aggression and learning ability are affected by the early physical environment (reviewed in Huntingford, 2004) and the early social environment (reviewed in Brown and Laland, 2001). The most detailed body of knowledge, including details on neuroendocrine development and its disruption by traumatic events that lie behind many of the lifelong effects, stems from studies on rodents and primates, including humans. Despite constituting two different mammalian orders, rodents and primates have been found to share similar mechanisms (reviewed in de Kloet et al., 2005). In pigs, such mechanisms have received little research attention. However, similar early environmental influences are known to cause similar long-term effects in pig, rodent and primate behaviour and welfare, suggesting similarities in mechanisms.

Normal development of the stress regulation system requires a period of relative freedom from stressors in early infancy. This is one of the main reasons the why emotional and neuroendocrine reactivity of an individual is permanently affected by events in early life. During a so-called stress hypo-responsive period in early infancy, the developing brain responds selectively to different types of inputs. For example novelty as such has no adverse effects, neither do those negative events that are within the normal range in which the species has developed, such as occasionally missing nursing. However, traumatic events or repeated adverse events do disrupt normal development, e.g., by affecting the number of glucocorticoid and mineralocorticoid receptors formed in the brain, thereby making the animal less able to cope with stressful events in later life (reviewed in de Kloet et al., 2005). This effect has been studied in e.g., rodents, rhesus macaques and humans (reviewed in Pryce, 2008). Individual differences in the severity of the disruption are partly caused by genetics (reviewed in Schmidt, 2010), but, for the most part, the extent of effects depends on the nature and severity of the stressors (reviewed in de Kloet et al., 2005).

The quality of maternal care and its long-term effects have been the focus of a large number of rodent and primate studies. Rat pups receiving less maternal grooming than a control group during the first 10 days of life have been found to become more reactive to stress as adults. This is due to impaired coping mechanisms such as hippocampal glucocorticoid receptor messenger ribonucleic acid (mRNA) activation, demonstrating that sufficient maternal care is one of the inputs required for normal development of mechanisms for coping with stress (Liu et al., 1997). In humans, parental neglect is a well-studied risk factor for depression in later life. Neglect-like situations have been experimentally induced in rat pups and infant rhesus maqacues, resulting in later depression-like states such as reduced interest in rewards and reduced ability to cope with adverse events (Pryce et al., 2005). Full separation from the mother at a young age causes more severe effects than does low quality of care. Rhesus macaques separated from their mothers at 2, 3 and 4 months of age, i.e., considerably earlier than the age at which the young would start dispersing in the wild, show long-lasting detrimental changes in behaviour (Suomi et al., 1973). Similar effects have been found in rats, caused by the acute stress triggered by the separation event and by the subsequent lack of maternal care (reviewed in de Kloet et al., 2005). In addition to changes to physiological mechanisms for coping with stress, separation of rat pups from mothers also impairs the development of brain neurotransmitter systems such as the serotonergic and glutaminergic systems, which is one of the reasons such rats have increased anxiety as adults (reviewed in Holmes et al., 2005).

Early environments also affect cognitive development. The impacts on the developing brain include, among others, the degree of differentiation in pyramidal neuronal cells, which are important for cognitive functioning (Pascual and Figueroa, 1996) and the degree of complexity in dendritic fields, which bring in sensory information (Fernandez et al., 2003). When rat pups are reared in standard laboratory cages or in cages with added physical complexity, testing in later life reveals the rats with the standard-cage background are more fearful in novel environments, habituate more slowly and have an inferior capacity for learning and memory; their brain volume and mass are smaller, and their brains show less neural plasticity (reviewed in Simpson and Kelly, 2011). Similar findings have been reported in mice (Iso et al., 2007). These and other studies have shown that inputs from a complex environment are a necessity for the development of sufficient neural plasticity and other aspects of normal brain development, including those brain characteristics needed to develop the full behavioural potential of the species (Rosenzweig and Bennett, 1996). Within certain limits, mild adversities may shape the phenotype in an adaptive way that may be even beneficial for adult welfare. One example is the so-called handling protocol with mice, i.e., 15 min of separation of the pups from the mother, which gives a boost to their later coping with stress (Luchetti et al., 2015). However, when the stress is too intensive with regard to the coping ability of the young of the species, it often results in permanent detrimental consequences.

For some aspects of physiology and behaviour, there is a time window called a critical period, during which specific environmental inputs are needed to enable normal brain development. The consequences of the success or failure of this to happen are permanent (reviewed in Knudsen, 2004). For example the stress hypo-responsive period discussed above, during which an animal needs to be free from traumatic, intensively stressful events to develop a normal stress regulation physiology, is from Day 4 to Day 14 after birth in rats (reviewed in Schmidt, 2010) and from Day 1 to Day 12 in mice (Schmidt et al., 2003). Motor development is another example. Rats prevented from normal locomotion from the third to fifth week of life become permanently unable to walk normally (Walton et al., 1992). Cognitive and emotional benefits gained by rats from living in a physically complex environment are most extensive and longest-lasting if the complexity is present from the first month of life (reviewed in Simpson and Kelly, 2011). Socialisation to one's own species, and to other species such as humans, also depends on inputs during a critical period (Freedman et al., 1961). Lack of sufficient socialisation to people results in anxiety or fear when approached or handled in later life (reviewed in McCune, 1995). The extent of socialisation depends on the duration of daily interaction and on the experience not being aversive (reviewed in McCune, 1995). Similarly, socialisation to one's own species requires exposure during the critical period. A milder form of insufficient socialisation is caused if the early environment is socially less complex than the normal social structure of the species. For example when infant rhesus macaques are isolated from the mother and reared with only a same-age conspecific, they will later react abnormally aggressively to unfamiliar conspecifics (Harlow, 1965).

4.1.2 Current state of knowledge in pigs

Most of the research on early environments and their long-term effects on pigs has involved comparisons between commercial-type management systems and modified versions of the same systems. In studies on physical environments, the most common approach has been to add a small number of features – such as more space, substrates or objects – to commercial-type pens, and to use identical or similar pens without added features as a control treatment. In some studies, the treatments compared have had several physical differences, such as comparing commercial-type pens to outdoor enclosures or alternative indoor farrowing systems. In studies on social environments, the experimental interventions have usually involved modifying the social groupings and ages of transition in commercial management systems, such as comparing group housing of lactating sows to the prevailing single-housing system or comparing the effects of different weaning ages. The parameters measured in the studies have often included various combinations of the following: behavioural indicators including the frequency and duration of play and agonistic behaviour; oral-nasal manipulation of objects, substrates and penmates; reactions to novelty, such as the latency to approach a novel object; physiological indicators such as diurnal rhythm of cortisol secretion, as well as performance and health parameters such as weight gain, skin lesions and mortality.

Most of the experimental modifications to commercial-type physical and social environments have resulted in measurable effects on piglet behaviour during the time that the piglets were living in the respective experimental and control environments. Such immediate effects on behaviour in the experimental groups have included, e.g., more exploration of substrates and objects, less oral-nasal manipulation of other pigs, less fearfulness in novel situations and more play behaviour, as compared to control piglets in conventional pens. Long-term effects persisting after transfer of the piglets from the experimental and control groups to identical post-weaning environments have only been found in some of the studies and seem to be more dependent on the specifics of the interventions. When found, such effects have included, e.g., less agonistic behaviour in some situations such as competition over food, as well as more exploratory behaviour, less belly nosing and less tail biting (reviewed in Vanheukelom et al., 2012). Long-term effects are found more frequently in studies involving transfer of piglets from experimental pre-weaning environments to experimental post-weaning environments and from control pre-weaning environments to control post-weaning environments, but in these cases it is challenging to disentangle the beneficial effects of the early-life environment from those of the current environment. Current environments have a substantial influence on pig behaviour, in some cases overriding the effects of earlier interventions. For example, the prevalence of tail biting in growing-finishing pigs depends more on the availability of straw at the time than on the earlier environment before weaning (van de Weerd et al., 2005). Similarly, although non-aversive human handling of young piglets reduces later fear of humans, this effect can partially be undone by aversive handling in later life (Hemsworth and Barnett, 1992).

In addition to the environments themselves, change from one environment to another also exerts an influence. For example in group housing systems during lactation, one of the key elements for success appears to be changing the social and physical environments gradually and not abruptly at the times around gestation, farrowing, grouping and weaning (Wattanakul et al., 1998; van Nieuwamerongen et al., 2014).

4.1.3 Relevance to pig production

Some countries have passed legislation to ban practices that are considered problematic for animal welfare, such as tail docking. For the most part, however, alternative systems to improve animal welfare can be widely adopted only if they also increase the economic profitability of production. This applies to changes in any level of pig production, be they modifications in existing practices, developing new pen or farm designs or management practices or, the least common approach but possibly the one with the most future potential, re-thinking the entire concept of intensive farming.

Of the lifelong consequences of early environments that have been identified in pigs so far, some do affect production-related parameters. For example, severe forms of tail biting cause economic losses because of carcass condemnations at slaughter (Harley et al., 2014), and post-weaning incidents of severe tail biting can be reduced by adding complexity to the pre-weaning environment (Telkänranta et al., 2014). However, there have been insufficient studies to design details of such an intervention to keep the added production costs at a lower level than the added economic benefit from reduced tail biting, and it is not yet known whether such an improved cost-benefit balance is possible without changing other aspects of the production environment. Similarly, some designed alternative farrowing pens can improve piglet survival, growth rate and the number of farrowings per sow, but they have higher production costs, and there is as yet not enough data to determine whether other possible long-term benefits are economically sufficient to offset the costs (Baxter et al., 2012). Some other welfare improvements appear not to convey economic benefits under the current type of intensive production environments. Allowing litters to interact from 2 weeks of age reduces aggressive interactions and stress as compared to the common practice of mixing at weaning, but does not affect overall weight gain (Wattanakul et al., 1997a,b).

Studies on meat quality, comparing pigs in different systems from birth to slaughter, have usually found very small correlations between welfare and meat quality (Beattie et al., 2000) or no effect (Hill et al., 1998). In some studies however, outdoor-reared pork has been rated higher than indoor-reared pork in terms of flavour and colour (Yonezawa et al., 2012). If the early environment changes the stress responses of pigs at the time of transport and slaughter, this has the potential to impact on meat quality. However, there is insufficient information concerning in which marketing environments such improvements in meat quality alone could translate into substantial enough increases in consumer prices to offset the extra costs.

Consumer perception of animal welfare is another factor that can potentially impact the economic feasibility of welfare improvements. Pig welfare, early-life issues included, is already discussed in the media and among the public. For surgical castration, some countries have already adopted less painful alternatives, and there is a growing interest in immunocastration in several other countries (Vanhonacker and Verbeke, 2011). Tail docking is another early-life issue raising public concerns in some countries (reviewed in D'Eath et al., 2014). In some major pork-producing countries, such as in China which houses more than half of the pigs in the world, public discussion on pig welfare is at a nascent stage (You et al., 2014), but concern among the public may in the future become a more prominent factor affecting the pork industry.

4.2 Influences of the physical environment

In this chapter, the term physical environment will refer to any physical features that can enable or restrict behaviours or otherwise affect piglets' physiology, emotional state, cognitive processes or physiological and neurological development. The physical environment, therefore, comprises, e.g., the quantity and quality of available space, objects and substrates, as well as anything else the animal perceives via its sensory system, such as smells, sounds, sights, tactile stimuli and painful events. For some of these factors, such as feed, pathogens and air quality, the influence on welfare is largely mediated by their effects on health, and therefore they are touched upon only briefly in this chapter.

4.2.1 Functions of the physical environment

Despite the changes in pig morphology (including reduced brain size, Kruska, 2005) and reproduction during the history as a domesticated animal, the functioning of the pig brain still is essentially similar to that of the ancestral wild boar. An important part of brain development takes place after birth. Normal development of the brain partly depends on environmental inputs similar to those that would have been encountered by wild boar piglets in the environments in which the species evolved. Such environments contain a certain range of sensory stimuli, spatial dimensions, interaction with materials, novelty and cognitive challenges. This is why scarcity of stimuli and scarcity of positive emotions elicited by successful environmental interactions result in suboptimal levels of some of the neurotransmitters required to maintain homeostasis in the brain. Developmental processes in the piglet brain have also evolved to incorporate some of these environmental inputs as necessary modulators of brain development. Long-term welfare of piglets is therefore positively affected by the presence of the right types of environmental input needed for normal development – and negatively affected by wrong types of environmental input that will disrupt developmental processes if experienced during a sensitive window in ontogeny. Furthermore, early learning may also have long-term consequences on behavioural development, but this has received less research attention so far.

Another consequence of similarities in brain functioning to that of the wild ancestor is retaining the ancestor's behavioural needs. The term refers to behaviours for which the motivation is internal rather than caused by external events; performing the behaviour is self-rewarding and thwarting of the behaviour results in frustration. The extent of fulfilment or thwarting of behavioural needs constitutes one of the immediate effects of the environment on piglet welfare. Immediate welfare also depends on the presence of environmental factors eliciting positive emotions, such as the appetitive and consummatory phases of pleasure (e.g., first anticipating or working for something and then engaging with it), play execution and social bonding; and on the absence of aversive experiences such as pain, fear, excessive frustration or thermal discomfort. Furthermore, the environment affects immediate welfare by either enabling successful allostatic processes with regard to e.g., thermoregulation, nutrition and health; or by making it so difficult for the animal to attain appropriate levels of these that the animal's welfare is compromised by the excessive allostatic load. The concept of allostasis also provides a useful framework for discussing emotional states. Just as it has evolved to depend on the availability of certain environmental inputs during early ontogeny, the pig brain also has evolved to function in an environment with a range of complexity and stimuli signalling opportunity for rewarded action such as finding food. Domestic animals therefore still retain the need for sufficient environmental stimuli and positive emotions in order to maintain normal levels of brain neurotransmitters.

For any aspect of a physical environment, the effect on welfare depends not only on its characteristics as such, but also on the extent of potential interactions that the animal can have with it. In addition to objects and substrates, this applies to the complexity of available space, as an animal's welfare is also influenced by its ability to control its own physiological and emotional states by moving between different environments.

One of the frequently occurring concepts in connection to environments of farmed animals is enrichment. The term has been used with varying definitions. Some authors (e.g., Simpson and Kelly, 2011) define enrichment as any stimuli added to standard housing. Others (e.g., Newberry, 1995) propose the term should only be used when such an addition has some demonstrable benefit to the animals. One of the proposed definitions specifies that enriched environments enhance the well-being of animals by allowing them to perform more of their species-specific behavioural repertoire and accommodating a larger range of behavioural choices (van de Weerd and Day, 2009). It has also been proposed that the term enrichment could, in many instances, be replaced by more specific definitions of what is being added, such as rootable substrates or sensory stimuli, as different enrichments serve different functions and therefore have different effects on welfare.

4.2.2 Immediate effects on behaviour and welfare

In studies on piglet behaviour in different environments, the most substantial differences have been found when comparing outdoor environments to commercial-type indoor pens. Piglets reared from birth in outdoor systems with paddocks have been found to perform more exploration, more rooting, more social play, more consumption of solid feed, less belly-nosing and less fighting than indoor-reared piglets, both before and after weaning, as well as less teat-directed activity before weaning (Cox and Cooper, 2001; Hötzel et al., 2004; Nakamura et al., 2011).

When comparing commercial-type indoor pens to modified versions of indoor pens, the most commonly tested intervention has been to add materials for chewing or rooting, either from birth or from several days later. Studies involving adding materials to farrowing pens have shown that piglets reared with straw, logs and branches have been found to interact with them frequently and to spend less time nudging and tail-biting littermates and manipulating pen floor and walls than control piglets in pens without added materials (Petersen et al., 1995). Piglets with a tray of peat, replenished daily, perform more foraging-type snout activity and gain more weight than piglets in a control group, even when both groups also are provided with a tray of dry feed (Vanheukelom et al., 2011).

In order to find solutions compatible with slatted or partly slatted pen floors, that are widely used in the pig industry, some experiments have focused on substrates and objects that do not risk obstructing the manure removal system. Piglets with sisal (also known as manilla) ropes suspended on the walls of the farrowing pens, or with shredded paper available in a box, show a shorter freezing time in a novel arena test, suggesting a lower level of stress, as compared to control piglets from ordinary barren farrowing pens. Of these two materials, paper elicits more activity than rope (Lewis et al., 2006). A combination of sisal rope and sheets of paper provided from birth has been shown to reduce oral-nasal manipulation of penmates (Telkänranta et al., 2014; see Fig. 4.2). In another experiment, piglets reared from birth with a jute

Figure 4.2 An example of studies showing long-term effects of early environments: providing sisal ropes and newspaper in farrowing pens reduced tail biting after weaning (Telkänranta et al., 2014). Such interventions can provide some of the environmental complexity that is needed for normal development of the piglet brain.
Source: Credit: Helena Telkänranta, University of Helsinki.

(also known as burlap) sack suspended on the pen wall show less tail and ear damage at weaning, and if housing with jute sacks continues after weaning, the difference in damaging biting behaviours including tail biting also persists (Ursinus et al., 2014a). With at least some materials, such as wood and rope for weaned piglets, the activity-eliciting effect of simultaneously provided materials has been additive (Trickett et al., 2009). The findings so far have shown that at least some materials for manipulation do have behavioural relevance for young piglets. However there are no systematic studies as yet on preferences among, or perceptions of, different materials by young piglets. Neither are there studies on whether such preferences and perceptions change after the neonatal period and over the subsequent weeks.

In addition to materials themselves, their quantity, location in the pens and other details have considerable influence on the resulting welfare benefits, or lack thereof. In commercial-type pens with added objects for manipulation, pigs often show behavioural synchrony in using the objects, and suckling piglets show a higher degree of synchrony than weaned piglets and growing pigs (Docking et al., 2008). If the quantity of objects or substrates is insufficient for simultaneous use, part of the potential behavioural benefits will not materialise, and in some cases there may be added stress caused by competition. For example, in an experiment providing one straw dispenser per pen for weaned piglets, there was no difference in tail and ear lesions and a higher number of aggressive encounters as compared to the control group, suggesting competition over the single straw dispenser had countered the beneficial effects of access to straw (Bulens et al., 2016). With regard to locations of objects or substrates, indoor pens with commercial-type dimensions require substantially more precise selection of locations of the materials than outdoor enclosures or paddocks, because in constrained spaces even a small difference in location can cause relatively large differences in the actual availability or perception by piglets. For example, altering the location of a straw dispenser in a farrowing pen has been found to have measurable effects on udder-related activity, weight gain and weaning weight of piglets (Bulens et al., 2014).

Olfaction is one of the most important sensory modalities for the pig. Feeding creeps with different flavouring agents in a daily sequential order increased the frequency of visits to the creep feeder and the feed intake of suckling piglets (Adeleye et al., 2014). In an experiment providing weaned piglets with objects scented with different aromatic compounds, the piglets were most attracted by, and showed longer-lasting interest in, the natural aromas of moist soil, grass and dried mushrooms, while synthetic strawberry aroma elicited less interest, and synthetic orange and vanilla aromas elicited even less. Novelty of an aroma also increased interest. Compared to a control group with similar objects with no added aromas, the piglets with aromatised objects showed less agonistic behaviour (Nowicki et al., 2015). Another approach to species-relevant odours in piglets is the use of maternal pheromones. Treating weaner pens with synthetic maternal pheromone an hour prior to the arrival of piglets has been shown to reduce fighting-induced lesions after mixing the litters (Guy et al., 2009). The effect of olfactory stimuli may also be the reason why piglets weaned and transported at 1 or 2 weeks of age show a less pronounced increase in blood glucose, blood lactate and haematocrit if transported with straw bedding (Roldan-Santiago et al., 2015). Although olfactory and auditory stimuli are among the most relevant for pigs, other sensory modalities also play a role in how piglets experience their environment. For example, temperature is an important criterion when selecting a place to sleep in, but it has also been found that from the first week of life onwards, piglets prefer a dark sleeping place over an illuminated one (Larsen and Pedersen, 2015).

As the immediate welfare effects of manipulable materials are mediated by experiences involving pleasure, it also is possible to amplify the effect of a given quantity of material by first generating anticipation. This prolongs the appetitive phase of pleasure, experienced before the consummatory phase. It has been found that if deliveries of portions of straw and seeds for piglets during the weeks before weaning are preceded by a sound cue, the piglets show less aggression both before and after weaning, less injuries after weaning and more play behaviour after weaning, as compared to piglets receiving identical portions without the sound cue (Dudink et al., 2006). A potential explanation is an improved mood state as a cumulative effect of pleasurable experiences. Such a protective mechanism caused by a cumulative effect of positive experiences could also be part of the causal mechanism for the findings that outdoor-reared piglets show less intensive stress reactions: for example, when piglets' ears are pierced at weaning, outdoor-reared piglets show a less pronounced increase in plasma and salivary cortisol levels than indoor-reared piglets (Yonezawa et al., 2012).

4.2.3 Development of stress regulation mechanisms

The environment during the first weeks of a piglet's life has long-lasting effects on the development and functioning of the endocrine system for stress regulation. Studies have shown, for example, that when piglets have been reared in outdoor paddocks or in ordinary barren indoor pens until weaning and moved identical environments after that, some effects persist into adulthood: the indoor-reared group had a higher basal cortisol level and showed a more pronounced cortisol response to a restraint stressor in adulthood (de Jonge et al., 1996). Long-term effects have also been found when comparing different types of indoor pens. In one study, piglets were reared in indoor pens with either ordinary farrowing crates or with added pen space, substrates and non-crated mothers. From weaning onwards, both groups were housed in identical environments. No differences in physiological stress responses were found at weaning, but when transported to slaughter at the age of 6 months, the group from the barren early environment had increased salivary cortisol concentrations immediately after transport and a decrease in meat pH after slaughter (Chaloupková et al., 2007a). In another study, piglets were reared for the first 4 weeks in either ordinary barren pens or in pens with a thin layer of wood shavings and chopped straw on the floor. At 5 months of age, the group from a barren early environment showed more tail biting and a blunted circadian rhythm of cortisol secretion (Munsterhjelm et al., 2010). In other species such as humans, such a blunted rhythm occurs in connection to chronic stress (Burke et al., 2005). In pigs, the mechanisms have not yet been studied in detail. It is therefore not yet known whether a barren early environment impairs the development of physiological coping mechanisms for stress, which would lead to both a blunted cortisol rhythm and behavioural disturbances; or whether a barren early environment leads to abnormal behavioural development and hence behavioural disturbances, which in turn would cause stress and hence a blunted cortisol rhythm, or both.

For other neurophysiological processes linked to welfare, there are similar questions awaiting investigation. For example, measurements of heart rate and heart rate variability in tail-biting, tail-bitten and non-involved pigs have shown that both biters and victims have dysfunctional autonomic regulation, indicated by their suppressed parasympathetic tone (Zupan et al., 2012). The effect is likely to be not entirely genetic but to have at least partially environmental causes, as indicated by another experiment testing the effect of a food-rewarded operant task on pigs from 2 to 4 months of age. Having experienced such cognitive stimulation, and the positive emotions it elicited, resulted in an improved parasympathetic tone as compared to a control group (Zebunke et al., 2011). This experiment also illustrates one of the many interactions between cognitive processes, emotional states and physiological responses.

4.2.4 Cognitive development

Studies in a wide range of vertebrates have shown that the physical complexity of the early environment has permanent effects on cognitive development. The effect is mediated by neurodevelopment during early ontogeny requiring adequate inputs from the environment. A more complex environment results in e.g., a larger number of synapses and more complex dendrite formation. This is the main reason why barren early environments cause impaired cognitive functioning.

There are few studies on the specific mechanisms in pigs, but studies do indicate that the lack of complexity in conventional production systems results in impoverished cognition. For example, pigs reared in conventional pens and tested at 3 months of age are slower to learn operant tasks and maze-navigation tasks than pigs reared from birth in pens with added space, straw and peat (Sneddon et al., 2000). Deficiencies in cognitive development may also have welfare implications beyond cognitive abilities. For example piglets given daily tasks of navigating a maze before weaning show lower fear responses post-weaning than a control group without maze experience, suggesting that cognitive stimulation in the form of spatial learning yields welfare benefits (Siegford et al., 2008). Studies in weaned pigs at a later age have shown that adequate cognitive challenges have a positive effect on some physiological indicators of welfare. Two- to four-month-old pigs trained to recognise and localise an acoustic signal indicating a small food reward have been found to have improved values of immunological parameters, such as immunoglobulin concentration and T-cell proliferation, and better wound healing as compared to a control group (Ernst et al., 2006).

4.2.5 Behavioural development

Long-term effects of early environment on later behaviour are multifactorial, mediated by e.g., development of stress regulation mechanisms, cognitive abilities, associations formed during early learning, extent of learned social skills, and cumulative effects of experienced emotional states. In piglets, most studies so far have focused on testing for the existence of behavioural effects of different early environments, and therefore less is known as yet about the mechanisms mediating these effects. For example, the existence of an effect of learned associations on later behaviour has been shown in a study in which piglets, pre-weaning, heard classical music during daily access to a straw-bedded play arena. Hearing the same music after weaning elicited increased play behaviour even when no longer accompanied with access to the play arena (de Jonge et al., 2008).

Of abnormal behaviours occurring in pig production, tail biting is among the most detrimental in terms of impaired welfare as well as economic losses. The causes of tail biting are multifactorial, including, e.g., deficiencies in the quality and quantity of feed, insufficient feeding space, suboptimal air quality and lack of materials to manipulate. Epidemiological studies on farms have suggested that the prevalence of tail biting is also influenced by pre-weaning and post-weaning environments. Farms with the practice of daily adding straw in farrowing pens have greatly reduced prevalence of later tail biting (Moinard et al., 2003). Farms where weaner pens have solid floors, enabling substrate use, and a moderate number of piglets per feeding place also have less tail biting at a later age, as compared to farms where weaner pens have partially or fully slatted floors or there is more competition over feed (Smulders et al., 2008).

Experimental studies have found that, when there is only minimal added space or materials in the early environment, this is not sufficient to protect from later tail biting. When the intervention in farrowing pens is more substantial, effects in later life do arise. It has been found that providing piglets in farrowing pens with paper, replenished daily, and sisal ropes does result in reduced tail biting in later life, as compared to piglets with no added materials in farrowing pens, when both groups of piglets are housed in identical weaner pens with wood shavings replenished daily (Telkänranta et al., 2014). However, later environments also have a substantial effect. Even though tail biting can start already before weaning, individuals that have started to tail-bite do not always continue it, and individuals that have not tail-bitten before can start doing it later in life (Ursinus et al., 2014b). In general, the current environment has a greater effect on tail biting than the past environment does (van de Weerd et al., 2005).

4.2.6 Interplay of past experiences and current environment

Long-term effects of early environmental conditions partly depend on the types of later environments the pigs are housed in. Some studies have found that when a later environment, such as a growing or finishing pen, contains even a small quantity of substrates, the beneficial effects are more pronounced if the pigs also have had early experience of substrates (Day et al., 2002). One of the likely reasons is that pre-weaning experiences have an influence on how piglets perceive and value the features in their later environments (Oostindjer et al., 2011).

When reducing tail biting by providing substrates such as straw to manipulate, the most effective intervention is to provide substrates pre-weaning as well as post-weaning, resulting in a lower prevalence in tail biting as compared to using substrates post-weaning only. On the other hand, if piglets have substrates pre-weaning but are transferred to a barren post-weaning environment, later prevalence of tail biting is often higher than in piglets transferred from a barren pre-weaning environment to a barren post-weaning environment (Day et al., 2002; Munsterhjelm et al., 2009). Behaviours likely to indicate stress, such as increased inactivity and belly-nosing, are also more prevalent in piglets transferred at weaning from substrate-containing to barren pens, as compared to piglets transferred from barren to barren pens (Vanheukelom et al., 2011). Transfer to an impoverished environment as compared to the previous one therefore has welfare effects of its own.

One of the factors likely to affect pig welfare is the stress caused by the abrupt transitions from one environment to another that pigs undergo on most commercial farms, such as the transition from farrowing pens to weaner pens. Reducing the stressfulness of weaning may therefore have potential in improving the piglets' behavioural responses to, and welfare in, their post-weaning environment. For example, providing a mixture of materials such as straw, peat, wood shavings and branches in weaner pens has been found to improve growth and feed efficiency and reduce diarrhoea in newly weaned pigs, suggesting a milder stress reaction than in the control group without added materials (Oostindjer et al., 2010). It may also be possible to slightly reduce the stressfulness of transition to new environments by providing objects with a familiar odour in the new environment, although there is has been only little research on this so far.

There still are several open questions regarding the interplay of past experiences and current physical environments. One of them is the potential long-term effect of traumatic, albeit brief, early experiences such as tail docking, tooth clipping and castration. It is not yet known whether they can e.g., increase anxiety in general and thus impair the ability to cope in new environments.

4.3 Influences of the social environment

Pigs are a highly social species and, for the young piglet, the most important behaviours in its early days are the interactions with its mother and littermates which regulate nutrition, thermoregulation and social development. Strong social bonds are formed which persist long after weaning (Newberry and Wood-Gush, 1986). It is therefore not surprising that the social experiences in early life can have long-lasting effects.

4.3.1 The importance of the mother

The most important social figure in the early life of the pig is its mother. Under natural conditions, a piglet's survival is critically dependent on the interactions that it has with her and, as a result, strong bonds are formed whose breakage causes great stress (Iacobucci et al., 2015). The specific odour of the mother is recognised in the first day of life, and her vocalisations by 3 days of age (Horrell and Hodgson, 1992) and separation results in distress vocalisation and frantic searching behaviours to re-establish contact. Information on the consequences of complete absence of maternal interaction comes from studies of piglets in artificial rearing systems, which have been most widely used in biomedical research, or with caesarean derived piglets removed from maternal contact to establish pathogen free status (e.g., Miniats and Jol, 1978). Because piglets which have not received colostrum show impaired development of the gut and immune system, resulting in lifetime compromise of health (Varley et al., 1986), it is more common to allow a brief period of suckling from the dam before removal. This is generally the case with the artificial rearing systems which are now becoming more commonly used in commercial pig production. As a result of increasing prolificacy of sows, the number of piglets born now often exceeds the number of available teats of the mother (see Baxter and Edwards, Chapter 3 : Piglet mortality and morbidity: inevitable or unacceptable?). Artificial rearing systems can provide a simpler alternative to the use of nurse sows for rearing these supernumary piglets, which are removed from the sow at 1–2 days after birth and housed in small groups fed on liquid milk replacer (Baxter et al., 2013; Rzezniczek et al., 2015).

Because of the strong survival value of suckling behaviour, young piglets spend long periods of time in udder-directed sucking and massaging behaviours to stimulate milk production and let down by the sow (Fraser, 1980). In the absence of the sow, such behaviours are redirected to other objects. This may be to littermates if piglets are housed in groups (Rzezniczek et al., 2015) or to other inanimate objects in the environment if no social companions are present (Noyes, 1976). Provision of a feeding nipple, or artificial udder, can serve as a focus for sucking and massaging behaviours and reduce the expression of such behaviours directed towards other piglets in comparison with trough feeding (Widowski et al., 2005), although it has been noted that piglets which have first experienced suckling from their dam are harder to train to feed from an artificial nipple than are naïve piglets. Widowski et al. (2005) noted that the behaviours of belly-nosing and of chewing other piglets showed a different temporal pattern in relation to feeding, suggesting that they might have a different motivational origin.

The largest body of literature on long-term consequences of modifying social influences from the mother come from studies of weaning age. In natural conditions, weaning is a gradual process taking 3–4 months to fully complete, during which time piglets have regular social contact with the mother while gradually increasing nutritional independence. Economic pressures in the pig industry have lead to a progressive reduction in weaning age in order to facilitate earlier rebreeding of the sow, and hence a higher number of piglets produced annually. As a result, weaning at 3–4 weeks of age is now the norm in Europe, whilst in other countries weaning at 2–3 weeks is still common. Early weaning differs from artificial rearing discussed previously, in that it usually involves not only concurrent removal from the mother and relocation to a new environment, but also a transition from liquid to solid feed, but many of the behavioural consequences are the same. As observed in artificial rearing systems, early weaning leads to a greatly increased prevalence of redirected sucking and massaging behaviours. These are most commonly expressed as belly-nosing and chewing behaviours directed to other piglets in the group (Fraser et al., 1998) and can persist beyond the immediate weaning period. The extent of these behaviours is directly influenced by the age at which abrupt weaning occurs. Thus, at a similar chronological age in later life (7 weeks of age), piglets weaned at 7 or 14 days of age showed a higher amount of belly nosing behaviour than those weaned at 28 days (Worobec et al., 1999). Few studies have looked at the lifetime consequences of early weaning, but there is some evidence that behavioural effects can persist for many months. Piglets weaned at 12 days of age still showed greater nosing and chewing of other pigs throughout the 3-month grow-finish period, despite no differences in feeding or drinking behaviour by this stage (Gonyou et al., 1998). However, Hohenshell et al. (2000) failed to find long-term differences in penmate-directed behaviours between piglets weaned at 10 or 30 days of age, with the large difference apparent at 6 weeks of age no longer detected between 7 and 23 weeks of age. Despite the absence of behavioural differences, long-lasting physiological changes were detectable in the pigs. Pigs weaned at 14 days showed a greater increase in plasma cortisol in response to isolation and blood sampling at 9 weeks of age, although no differences in response to handling and transport were apparent at the time of slaughter. It has been shown in rodents that neonatal stress can result in heightened stress response during adolescence (e.g., Liu et al., 1997). They therefore hypothesised that, because piglets show a significant decrease in cortisol over the first 2 weeks of life, the elevation of cortisol at the time of early weaning (14 days) might interfere with the programming of the hypothalamus–pituitary–adrenal cortex axis (HPA) axis and cause long-term dysregulation. In support of this, they also measured greater mRNA for pro-opiomelanocortin (POMC) at the time of slaughter in the early weaned pigs, suggesting greater activation of the HPA axis. These pigs also failed to show a correlation between mRNA for POMC and the adrenal adrenocorticotropic hormone (ACTH) receptor, whereas a significant relationship existed in the later weaned pigs. However, the role of early weaning stress in the programming of the HPA axis is still ambiguous, since Jarvis et al. (2008) found no evidence from a comparison of weaning ages of 12, 21 or 42 days that there was any long-lasting effect on the HPA axis; baseline salivary cortisol, plasma ACTH and cortisol in response to a restraint and isolation test, and expression of corticotropin-releasing hormone (CRH) mRNA in the paraventricular nucleus of the hypothalamus were all similar between the weaning ages at 90 days.

Whilst most studies have focussed on the consequences of complete removal from the mother, the profound behavioural differences that result make it interesting to speculate on the likelihood of more subtle consequences of different qualities of maternal care when piglets are reared by their mother. There are certainly production and health differences arising from variation between piglets in nutritional and immunological provision from the dam in early life, but differences associated with behavioural attitude towards the piglets have been less well studied. O'Connell et al. (2005) showed that the amount of belly-nosing shown by weaned piglets was influenced not only by weaning age (3 or 5 weeks), but also by the gestation housing conditions of the mother in the case of early weaning. They speculated that this might be a result of changed maternal behaviour in early life, since gilts reared in barren environments show more aggression and less maternal care towards offspring in the post farrowing period than gilts reared in enriched environment (Schouten, 1986). However, prenatal stress effects resulting from changed HPA activity in barren-housed gilts cannot be excluded.

There is also evidence that piglets learn skills from their mother during the lactation period which may have effects on behavioural development, at least in the immediate post-weaning period. Piglets which are able to interact with their mother during feeding show increased foraging related behaviours during lactation, and develop less belly-nosing and manipulatory behaviour in the first 2 weeks after weaning (Oostindjer et al., 2014). Anecdotal reports also suggest that piglets learn excretory patterns from their dam and that this can affect later maintenance of pen hygiene, though this is yet to receive scientific study.

4.3.2 Interactions with peers

Whilst the mother provides the hub for social activity, interactions with littermates also occur from a very early age. These may be competitive, as in the acquisition and defence of the best possible teat as the teat order is formed within the litter shortly after farrowing (Fraser, 1980), but are also cooperative during the coordinated initiations of nursing bouts (Špinka et al., 2011) and affiliative as the littermates rest together for warmth, learn normal species-specific social interaction patterns and engage in social play. Information on the behavioural development of piglets reared in total social isolation is scarce, although neonatal social stress induced by repeated early isolation can cause long-term changes in behaviour, neuroendocrine and immune regulation (Kanitz et al., 2004). Separating piglets from their litter for 2 h daily on days 3−11 of life resulted in reduced open-field activity, increased basal cortisol response and decreased lymphocyte proliferation. Six weeks later, the isolated piglets still showed significantly enhanced basal ACTH concentrations, higher interleukin-1β concentration, as well as greater glucocorticoid receptor binding, in the hippocampus and decreased CRH levels in the hypothalamus. When subject to an endotoxin challenge at 8 weeks of age, the piglets which had experienced early life isolation stress also showed increased intensity of vomiting, suggesting a brain-mediated sensitisation of adaptive responses (Tuchscherer et al., 2006). The presence of an age-matched peer diminished the behavioural and physiological stress responses shown in an early life isolation test, with this beneficial effect being more pronounced for a familiar than an unfamiliar peer (Kanitz et al., 2014). This demonstration that the degree of familiarity between piglets influences the effectiveness of social support in stressful situations, indicates that it is not only social bonds with the mother, but also social bonds with peers which are important in early life. In modern farming systems, these social bonds can be disrupted through cross-fostering during the lactation period, and the gradual development of social dynamics with peers can be challenged by the abrupt introduction of non-littermate peers during forced mixing for group lactation systems or early weaning.

Cross-fostering involves transfer of a piglet to a new nursing sow, in order to equalise litter size or piglet weight distribution amongst the available sows and give each piglet the best chance of securing a productive teat and thriving. However, the immediate effects of this procedure are the stress of separation from the piglet's own dam, mixing with unfamiliar piglets, and the need to establish a new teat order in order to obtain milk. When cross-fostering occurs very soon after farrowing, there are few behavioural consequences, as maternal recognition and teat fidelity are not fully developed. In contrast, fostering piglets older than 2 days can lead to aggression between resident and newly introduced piglets, piglet directed aggression from the sow and major disruption of suckling (Horrell and Bennett, 1981; Price et al., 1994). As a result, piglets within fostered litters grow more slowly than those in undisturbed litters, with adopted pigs being more affected than resident pigs (Giroux et al., 2000). The longer term effects of this disruption of a stable social relationship with peers have been most studied in the context of growth. Some studies have shown no post-weaning differences between fostered and non-fostered piglets (Giroux et al., 2000). Similarly, grouping low birthweight piglets with similar sized peers during lactation improved pre-weaning growth by reducing competition from heavier littermates, but this advantage did not persist after weaning (Douglas et al., 2014). However, the longer term effects of repeated social disruption in early life deserve further study.

Interestingly, fighting after weaning and co-mingling of litters has been shown to be less frequent in pens housing piglets from fostered litters, than in pens with piglets from previously undisturbed litters, with reduced prevalence of skin lesions during the first week (Giroux et al., 2000). This suggests that the previous experience of encountering and engaging in aggression with unfamiliar piglets during lactation modifies subsequent agonistic interactions. Such beneficial effects have not been found after those aggressive encounters in which the conflict is not resolved but instead intensifies over time, such as competition with siblings over udder space, which is exacerbated by the large litter sizes of today. Skok et al. (2014) found that the level of competition amongst neonatal piglets during suckling is reflected in intensified aggression in later life stages. They demonstrated that piglets which had a teat position in the middle section of the udder, where teat disputes occur with greater frequency, were more frequently involved in aggressive interactions when mixed at the time of weaning and that groups containing these piglets had a less stable social order.

In natural conditions, piglets leave the nest at around 2 weeks after birth and follow their mother back to the main sow group, where they encounter other piglets for the first time. In commercial practice, mixing with other piglets usually takes place at the same time as abrupt weaning, giving rise to the contemporary stressors of maternal separation, dietary change, separation from siblings if sorted by sex or weight and regrouped, as well as elevated agonistic interactions to establish a new social order amongst unfamiliar peers. Pre-weaning socialisation by allowing litters to mix during lactation, has been shown in many studies to diminish subsequent agonistic behaviour after weaning. Piglets allowed pre-weaning socialisation with other litters, starting at 10–14 days of age, subsequently show reduced post-weaning aggression and skin lesion scores when housed in multi-litter groups (Wattanakul et al., 1997a,b; Kutzer et al., 2009) and have been rated by observers in a Qualitative Behavioural Assessment as scoring higher for positive descriptive terms including 'content'/'relaxed' while control animals were more 'aggressive'/ 'dominant' (Morgan et al., 2014). The changes in aggressive behaviour observed after weaning as a consequence of early socialisation persist into later life. D'Eath (2005) assessed agonistic behaviour in more detail using resident–intruder tests at 2 weeks after weaning and subsequent mixing of pigs into new groups. He showed that pigs experiencing pre-weaning socialisation were more likely, and quicker, to attack a smaller unfamiliar intruder pig, and engaged in earlier but shorter fights after regrouping. The socialised pigs formed a stable hierarchy more rapidly than control pigs, suggesting that they had learnt social skills which benefited them in the longer term. A further interesting behavioural correlate of pre-weaning socialisation relates to the sexual behaviour of entire male pigs. Boars which were grouped at 2 weeks of age, and subsequently remained in these stable groups, showed less aggressive behaviour and had fewer skin lesions in comparison to boars mixed later in the growing period (Rydhmer et al., 2013). Whereas control pigs directed more aggressive behaviour towards non-littermates than towards littermates throughout the finishing period, socialised pigs did not show any differentiation, suggesting they had formed different social bonds with unrelated peers. The control pigs showed a higher frequency of mounting behaviour as they approached puberty, though this might have been an agonistic behaviour since testis weight and boar taint compounds at slaughter did not differ between the groups. Results suggest the possibility that there might be an early critical window for these beneficial socialisation effects, since Salmon and Edwards (2007) found that pigs mixed only once at the time of weaning (4 weeks) showed increased mounting behaviour in later life, and also heavier testis weight and increased fat and androstenone level in comparison pigs maintained from birth in litter groups.

4.3.3 Interactions with humans

In natural conditions, piglets do not have frequent encounters with animals of other species. However, domesticated animals have increased contact with humans, who must therefore be considered as a component of the social environment, and it is important to consider the implications of this for pig welfare. The pig–human interactions are extensively covered by Tallet et al. (Chapter 13: Pig-human interactions: creating a positive perception of humans to ensure pig welfare). Here we focus specifically on interactions with humans in the early life of piglets. In normal commercial practice, the main experiences that piglets have with people are negative. Early in life they may be subject to a number of painful interventions including tooth resection, tail docking, ear tagging/notching, castration and injections for delivery of iron supplements and vaccines. These procedures give rise to both extreme behavioural reactions indicative of distress and to acute elevation of blood cortisol (Sutherland, 2015). The extent to which these early painful experiences have long-term consequences has been little studied until recently, though based on the evidence relating to other early life stressors presented in this chapter it is likely that this will be the case. Piglets subject to neonatal tail docking showed greater fearfulness of humans in a voluntary approach test carried out 2 weeks later (Tallet et al., 2016).

The quality of general handling in the suckling period has also been shown to influence later piglet behaviour. Piglets from litters exposed daily, from Days 10 to 27 after birth, to a stockperson that was noisy and behaved threateningly and unpredictably during daily pen cleaning tasks showed greater avoidance of humans in a test at the time of weaning than piglets from litters with a quiet and careful stockperson (Sommavilla et al., 2011). Furthermore, this increased avoidance was specific to the ‘unpleasant’ stockperson and did not generalise to an unfamiliar person, showing the ability of even young piglets to discriminate between humans. Negatively treated piglets also showed higher frequencies of fighting and escape attempts, and reduced resting after weaning and regrouping, although feed intake and growth before and after weaning were unaffected. The results suggest that handling quality experienced in early life may further aggravate weaning stress.

Since the pig is a prey species, it is to be expected that, even in the absence of negative experience of people, their initial response should be fearfulness and avoidance. As piglets will inevitably be subject to human interaction during later stockman tasks, especially if retained as breeding animals, the potential benefits of reducing fearfulness have been investigated. A large body of work has investigated the effects of handling pigs in different ways on their subsequent fear of humans, and the consequences that this has for productive and reproductive function (reviewed by Hemsworth and Coleman, 2011). These treatments have generally been applied after weaning, where it has been shown that regular positive handling (stroking and quiet talking when pigs approach a human) induces contact seeking behaviour and reduces basal cortisol level. In contrast, negative handling (slapping or electric shock) or inconsistent handling induces avoidance and chronic physiological stress responses, while minimal handling gives intermediate results. The positive handling also resulted in improved growth rates and reproductive performance in both male and female pigs. Since the existence of a critical period for early socialisation has been identified and exploited in other species, this possibility was also investigated in the pig. Piglets were treated from birth to 8 weeks of age in one of three ways (Hemsworth et al., 1986). Some were artificially reared in a group with regular handling, some remained on the sow for 4 weeks but received regular handling and some remained unhandled except for routine husbandry tasks. When tested in later life, the handled piglets more readily approached humans, with no differences between sow and artificially reared animals. Closer investigation showed that treatments applied in the first 3 weeks of life had a greater effect on fear response to humans at 6 months of age than those applied at later times (Hemsworth and Barnett, 1992).

Another stimulus to research on the effects of early human contact has been the extensive literature in rodents showing that there is a sensitive period in early life when handling by humans can result in permanent changes in HPA axis function, behaviour and growth. Tactile stimulation increases the glucocorticoid receptor sites in the hippocampus, giving reduction in HPA response to stress, linked to greater resistance to pathogens and improved cognitive ability (Levine, 2005). In contrast to the handling treatments in the research of Hemsworth and collaborators, where handling was usually contingent on the voluntary approach of the pig, the rodent protocol involved forced handling which is expected to initially induce low level stress. De Olivera et al. (2015) demonstrated that a forced handling protocol in piglets from 5 to 35 days of age did also result in reduced fear of humans at 4 weeks of age, and modified behaviour in an open-field test in a way that indicated reduced general fearfulness. The physiological consequences of a forced handling protocol were investigated by Weaver et al. (2000), who removed piglets from the litter and handled them for 10 min per day for the first 14 days of life. When tested at 7 months of age, handled boars showed greater locomotor scores in the inner squares in an open-field test, greater plasma corticosteroid binding capacity and lower basal plasma concentrations of both total and free cortisol. However, no treatment effect was found on the HPA response to stressors or on glucocorticoid receptor expression in the hippocampus, hypothalamus or pituitary gland. Since the handled pigs showed greater plasma ACTH, but not cortisol, concentrations at the time of slaughter, it was suggested that a dysregulation of ACTH-induced cortisol release had been induced, with cumulative effects of stress-induced ACTH down-regulating adrenal sensitivity. Thus, while neonatal handling resulted in long-term alteration in HPA function, these changes did not mimic the rodent results, and gave no beneficial effect on growth. This difference between pigs and rodents may reflect the species differences in maternal behaviour. In rats, the effects of early handling seem to be mediated by increased maternal licking and grooming, whereas such maternal behaviours are not exhibited by pigs.

There is some evidence that, when animals have previously experienced positive emotional states in the presence of humans, human presence may ameliorate aversive situations; for example, previous positive handling has reduced heart rate and salivary cortisol concentrations in lambs following tail docking (Tosi and Hemsworth, 2002). This possibility lead Muns et al. (2015) to hypothesise that creating positive associations to humans in piglets' minds on the first day of life might reduce the stressfulness of the subsequent husbandry procedures. To achieve this positive association, they subjected piglets to human talking and caressing during six suckling bouts on the first day of life. These piglets had a reduced duration of escape behaviour during tail docking on Day 2, but showed no reduction in cortisol levels. Two weeks later, the piglets still showed a tendency for reduced duration and intensity of escape behaviour to human capture, suggesting reduced fear of humans. The mechanism is not known, but it may have been a combination of positive conditioning and of socialisation, as the latter has substantial and long-lasting effects if it takes place during the species-specific critical period for socialisation in early life. One of the crucial effects of socialisation is its impact on which species will thereafter be perceived as potential predators and which are not. In contrast to the process of socialisation, which only has a brief time window, learning by conditioning takes place throughout life. It adds more nuances to animals' perceptions of species and individuals, e.g., conditioned fear responses to specific persons as a consequence of earlier aversive handling.

4.4 Interactions of the physical and social environment

The environment in which a piglet finds itself at any given time is rarely physical only or social only, but comprises both. In addition to coexisting, physical and social factors in the environment can also affect each others' impact on piglets. The physical environment affects the social environment, e.g., when the quantity of available substrates or objects determines whether piglets are able to manipulate them in synchrony, or the extent of available space determines the extent of locomotor play behaviour possible. The social environment affects the piglets' ability to utilise their physical environment, e.g., by competition if there are insufficient resources such as feeding space. When studying effects of physical and social environments experimentally, an intervention in one can also have secondary effects on the other. For example, if one of the experimental treatments is an increased group size, this means either more physical space, which can contribute to any beneficial effects found, or more competition over the same space, which can affect the results in the opposite direction.

A typical example of an abnormal behaviour that has been found to have causes both in the early physical and early social environment is belly nosing. Probable causes include redirecting of suckling behaviour because of weaning at an early age (Bruni et al., 2008), redirecting of rooting behaviour because of lack of rootable substrates (Bench and Gonyou, 2006) and disturbed development of social behaviour because of constraints set by the physical environment on the range of possible social interactions (Li and Gonyou, 2002).

4.4.1 Additive effects of physical and social stressors

When piglets experience physical and social stressors simultaneously, the detrimental effects are often additive. For example in laboratory pigs, which in some countries are often kept in isolation, studies on physiological indicators of stress such as eosinophil count and tear staining have shown that the combination of a barren physical environment and social isolation results in a more intensive stress response than either of these stressors alone (DeBoer et al., 2015).

The additive effects of physical and social stressors are well illustrated by the differences between the usual weaning process in the pig industry as compared to weaning in the natural behaviour of pigs. In commercial farming, the weaning process not only takes place at an earlier age and an abrupt manner, but it also involves several simultaneous changes, both social and physical: separation from the mother, mixing with unfamiliar piglets, transfer to a different pen in a different room and a change from mainly suckling milk to only eating solid feed. Studies have shown that each of these is a stressor to piglets and that the distress response is intensified if these events take place simultaneously (Hötzel et al., 2011; Colson et al., 2012), whilst in some situations the distress response at weaning is considerably reduced if some of these stressors are absent (reviewed in Weary et al., 2008). Whereas the immediate effects of the distress response are well-studied and include, e.g., reduced weight gain, diarrhoea, vocalisation and, when mixed with unfamiliar piglets, aggression, the potential long-term effects have received less research attention so far.

As the effects of different environmental factors are in some cases additive, there are open research questions on which combinations of interventions in both in the physical and social environment could yield more substantial benefits than either of them alone. For instance, there is as yet limited knowledge on whether long-term effects of early-life handling stressors caused by conventional farming practices interact with the effects of the environmental interventions tested in the studies, because in most studies both the experimental and control groups have experienced the early-life stressors present in commercial-type environments.

4.4.2 Effects of the physical environment on the social environment

In addition to directly influencing the behaviour and welfare of piglets, the physical environment in the farrowing pen also affects the behaviour and welfare of the mother, which in turn have consequences for the piglets. For example, a non-crated mother has more opportunity to show maternal social behaviour towards the piglets as compared to a crated mother. Objects or substrates added to pens for piglets may also have partly different effects depending on whether or not the mother also has access to them.

Another major route through which a piglet's physical environment affects its social environment is the effect of the physical environment on the behaviour of the other piglets present. A number of studies has found a correlation between physical features of the pre-weaning environment and the extent of aggression later in life. Pigs that have been kept in conventional barren farrowing pens during their first weeks of life show more agonistic behaviour later in life as compared to pigs that have had access to rootable substrates before weaning (O'Connell and Beattie, 1999; Chaloupková et al., 2007b; Munsterhjelm et al., 2009). The effect is shown during competition over resources such as food, but not during more profound disturbances in the social environment such as mixing with unfamiliar piglets at weaning (Chaloupková et al., 2007b). The mechanism is mediated at least partly by the influence of environmental complexity on the development of play behaviour, which in turn affects formation of dominance relationships. Availability of substrates and objects stimulates play, and play in turn facilitates perception of the body weight of other individuals as the basis for forming a dominance hierarchy, because piglets learn about the effects of body weight during play-fight encounters. Pigs that have spent their first weeks in a barren environment, and therefore with limited opportunity for learning through play, have been found to later form their dominance hierarchy mainly by behaving aggressively instead of assessing each other's body weight. This is one of the main reasons why pigs with a background in a barren early environment fight more than pigs with a background in a more complex early environment (O'Connell and Beattie, 1999). In general, play behaviour facilitated by a suitable environment appears to be of fundamental importance for normal socio-cognitive development of piglets (Martin et al., 2015).

4.4.3 Effects of personality types on responses

Adverse effects of suboptimal early environments often vary between individuals. There is growing evidence that these differences are partly caused by differences in personality, i.e., in consistent individual differences in coping strategies and physiological reactions to emotion-inducing stimuli. In many species, several different personality traits have been identified, each trait forming an axis along which each individual animal is located at some point. Such personality axes are independent of each other in the sense that an individual's position on one axis does not predict its position on another axis. The actual neurological and emotional systems determining personalities are likely to be more complex than this, but the concept of personality axes has been found to function as a practical tool at the current stage of development of personality research.

One of the personality axes identified in several species, including pigs, is a continuum from active copers to passive copers. The closer an individual is to the active-coper end of the continuum, the more likely it will be to respond with some form of action when encountering a threat or an opportunity. The closer an individual is to the passive-coper end, the more likely it will be to respond by freezing or observing while behaviourally inactive. In piglets, this difference has been measured by a so-called backtest, in which a piglet is restrained in a supine position by an investigator, counting the number of escape attempts in a unit of time and classifying each piglets as either high-resisting or low-resisting. It has been found that in low-resisting piglets, the level of environmental complexity, such as the availability of substrates, has a more pronounced effect on play and oral-nasal behaviours than in high-resisting piglets (Bolhuis et al., 2004, 2005). Other findings include, e.g., that high-resisting piglets are less adept at reversal learning than low-resisting piglets, which may cause a higher likelihood of developing inflexible behavioural patterns (Bolhuis et al., 2004), and aggression at mixing with unfamiliar piglets at weaning shows differences in fighting strategies, although not in total fight duration (Melotti et al., 2011).

In addition to the activity-passivity axis of coping styles, as well as to other personality axes that are as yet unresearched in pigs, there are genetic differences in the propensity for tail biting (Breuer et al., 2004; Brunberg et al., 2011). It is not yet known whether these differences reflect personality-type differences, i.e., different coping strategies, or whether a higher propensity is caused by a deficiency in coping ability in general. Further research is needed to gain a more comprehensive understanding of the genetic causes for the individual differences that result in different short and longer term welfare consequences in similar environments. Another question requiring further research is whether there are causal relationships in the opposite direction too: whether and how the early physical and social environments modulate development of personality.

4.5 Conclusions and future issues

4.5.1 Conclusions

The environment during the first weeks of piglets' lives has long-lasting effects on behavioural development, cognitive flexibility, social skills and functioning of the endocrine system for stress regulation, each of which has substantial effects on their long-term welfare. The functioning of the pig brain retains substantial similarity to that of the ancestral wild boar. Its normal development in early ontogeny requires some key environmental inputs resembling those in the environments in which the species evolved. These include stable social bonds with the mother and siblings, learning social skills with other piglets encountered at the age when piglets in the wild would leave the nest, complexity of sensory stimuli, spatial dimensions, interaction with materials, novelty, cognitive challenges and positive emotions elicited by successful interactions with these. Insufficient availability of these inputs disrupts normal development, as do abrupt changes in environment and intense stressors, such as separation from the mother substantially earlier than the natural weaning age of the species. If several stressors are experienced simultaneously, their detrimental effects are often additive.

Tail biting, belly nosing and increased aggression are among the abnormal behaviours for which there already is a body of research showing that early-life factors contribute to the development of these problems – and which kind of interventions can be applied to reduce their prevalence in commercial farming. For several other aspects of development, research evidence already exists but further research is required to better understand the causal factors involved. Examples include the beneficial effects of social interaction with a non-crated mother, the immunological benefits from opportunities for rewarded learning, the reduction in fear responses as a consequence of improved spatial skills and the potential to reduce fear of humans by early socialisation. It has also become increasingly clear that the causal influences in early development, as well as in interactions between early experiences and later environments, form a complex network of interactions between different physical and social factors. As a whole, the field of studying the effects of early environments on later pig welfare is still at an early stage. Future research is expected to yield substantial advances in the understanding of the interactions and discoveries of more causal factors.

4.5.2 New research questions for the future

As is the case with all domestic species, the factors affecting pig behaviour and welfare are still far from fully understood. Long-term effects of the early environment of piglets have received relatively limited research attention so far, and there are a number of questions awaiting investigation. The following text provides some examples of questions arising from the current level of knowledge.

Meeting of the species-specific behavioural needs is one of the major components of welfare. For some behavioural needs it is not yet known at which age they first start manifesting themselves. For example, in pigs rooting and chewing are considered to be behavioural needs, and these behaviours start occurring early, long before weaning, but it is not known at how many days of age they become genuine needs. Another open question regarding behavioural needs in animals in general is how clear-cut is the border between behavioural needs and other behaviours that elicit positive emotions. For example pigs are highly attracted to investigate novel objects and environments, but it not known whether such exploration constitutes a behavioural need. In addition to the currently recognised behavioural needs in pigs (e.g., oral-nasal manipulation of the environment in the form of rooting and chewing, and constructing a nest prior to farrowing), it is possible that some other parts of the behavioural repertoire of the pig may also constitute genuine behavioural needs, in the sense of being internally motivated, self-rewarding and necessary for maintaining homeostasis of brain neurotransmitters. Some other behaviours will not meet all the criteria for a need but do elicit positive emotions, which would to some extent compensate for the stressors and understimulation in intensive farming.

Further research has also been called for on neurobiological effects of different enrichment materials and stimuli in order to better understand their different effects on the piglet mind (van de Weerd and Day, 2009). The same may apply to the neurobiological effects of the composition of feed. For example dietary tryptophan has been found to reduce plasma cortisol and noradrenaline in pigs at a later age (Koopmans et al., 2009) and the composition of feed has been found to affect the prevalence of abnormal behaviours in newly weaned piglets (Araújo et al., 2010).

Tail biting is one of the multifactorial abnormal behaviours for which the success in prevention would be better if the causal factors were more fully understood (Valros, Chapter 5: Tail biting). There appear to be three different types of tail biting, each with partially different causation (Taylor et al., 2010). Since these types differ in the motivational basis, they may also be influenced by different environmental factors in early ontogeny.

Cognitive input from the early environment is known to have permanent effects on development in other mammalian species studied, but so far there are few studies in piglets. One of the potential questions would be the role of novelty. Novelty is known to be highly efficient in eliciting object interactions in pigs, young piglets included. It is known from other species that, during attraction to novelty, the brain circuitry involving pleasure shows heightened dopamine activity, resulting in a pleasurable experience. It is not yet known whether a high enough level of dopamine activity, elicited by frequently encountering novelty, is necessary for the piglet brain to develop normally.

Sensory development has been found to partly depend on inputs from the environment in other species such as mice, but this has not been studied in piglets. In most pig production environments, the landscape of odours and noises is relatively monotonous as compared to the natural environment in which the piglet brain evolved. It is not yet known whether this lack impairs cognitive development and, if it does, whether this has welfare consequences. Adding sensory stimuli to production environments would be a relatively low-cost intervention as compared to other necessary additions such as substrates and objects. In other species, such as cats, it has been found that an artificial soundscape mimicking positive social vocalisations of the species can improve welfare in understimulated environments (Snowdon et al., 2015). The olfactory sense has especially extensive unused potential as a route to improve the welfare of domestic and other captive animals, including pigs and piglets. Adding olfactory stimuli that reduce stress or elicit positive emotions, as well as removing olfactory stimuli that elicit a state of alarm, could improve welfare in a number of environments and situations (Nielsen et al., 2015).

Critical periods are another aspect of early development in need of further research in piglets. A critical period in early ontogeny that has been extensively studied in rodents and primates is the stress hypo-responsive period, during which a relatively stress-free environment is a necessity for the physiology of stress regulation mechanisms to develop normally. Findings on long-term impacts of early environments on stress physiology in pigs suggest that a similar process may also occur during early development of piglets. Neurobiological findings in other species have shown that the development of stress regulation mechanisms is disrupted by both traumatic single events and repeated mild stressors, and, at least in rodents, the sensitive window in time coincides with a time when the pups in the wild would still remain in the nest. Should the same turn out to be the case in piglets, this would raise questions on long-term effects of some routine management practices. Single painful events in the case of piglets include tail docking, tooth clipping and castration, and possibly also the handling practice on some farms of picking up piglets by one hind leg which is likely to be painful. For repeated milder stressors, potential candidates include, e.g., the high concentration of atmospheric ammonia and other aspects of suboptimal air quality on many commercial farms, as well as large litter sizes resulting in increased competition over teats: even after the teat order is established, in large litters it is not always easy for piglets to fit at the udder simultaneously, though this situation usually is excacerbated from only the second or third week of life onwards.

On a more general level, while many of the early interventions that have been experimentally tested in commercial-type environments have yielded benefits that are measurable and in some cases substantial, they have not fully eliminated the behavioural disturbances and other welfare problems that occur in the control groups and do not occur in well-planned semi-natural environments, so are not an inevitable biological characteristic of the species. This is why further research is still carried out and needed in order to better understand the underlying causal factors behind these welfare problems, as well as to develop new types of commercially feasible production environments.

Abbreviations

ACTH adrenocorticotropic hormone
CRH corticotropin-releasing hormone
HPA hypothalamus–pituitary–adrenal cortex axis
mRNA messenger ribonucleic acid

References

Adeleye, O.O., Guy, J.H., Edwards, S.A., 2014. Exploratory behaviour and performance of piglets fed novel flavoured creep in two housing systems. Anim. Feed Sci. Technol. 191, 91–97.

Araújo, W.A.G., Ferreira, A.S., Renaudeau, D., Brustolini, P.C., Silva, B.A.N., 2010. Effects of diet protein source on the behavior of piglets after weaning. Livest. Sci. 132, 35–40.

Baxter, E.M., Edwards, S.A., 2017. Piglet mortality and morbidity: inevitable or unacceptable? In: Špinka, M. (Ed.), Advances in Pig Welfare. Woodhead Publishing, Duxford, UK.

Baxter, E.M., Lawrence, A.B., Edwards, S.A., 2012. Alternative farrowing accommodation: welfare and economic aspects of existing farrowing and lactation systems for pigs. Animal 6, 96–117.

Baxter, E.M., Rutherford, K.M.D., D'Eath, R.B., Arnott, G., Turner, S.P., Sandøe, P., Moustsen, V.A., Thorup, F., Edwards, S.A., Lawrence, A.B., 2013. The welfare implications of large litter size in the domestic pig. II: management factors. Anim. Welfare 22, 219–238.

Beattie, V.E., O'Connell, N.E., Moss, B.W., 2000. Influence of environmental enrichment on the behaviour, performance and meat quality of domestic pigs. Livest. Prod. Sci. 65, 71–79.

Bench, C.J., Gonyou, H.W., 2006. Effect of environmental enrichment at two stages of development on belly nosing in piglets weaned at fourteen days. J. Anim. Sci. 84, 3397–3403.

Boivin, X., Tournadre, H., Le Neindre, P., 2000. Hand-feeding and gentling influence early-weaned lambs' attachment responses to their stockperson. J. Anim. Sci. 78, 879–884.

Bolhuis, J.E., Schouten, W.G.P., de Leeuw, J.A., Schrama, J.W., Wiegant, V.M., 2004. Individual coping characteristics, rearing conditions and behavioural flexibility in pigs. Behav. Brain Res. 152, 351–360.

Bolhuis, J.E., Schouten, W.G.P., Schrama, J.W., Wiegant, V.M., 2005. Behavioural development of pigs with different coping characteristics in barren and substrate-enriched housing conditions. Appl. Anim. Behav. Sci. 93, 213–228.

Breuer, K., Sutcliffe, M.E.M., Mercer, J.T., Rance, K.A., O'Connell, N.E., Sneddon, I.A., Edwards, S.A., 2004. Heritability of clinical tail-biting and its relation to performance traits. Livest. Prod. Sci. 93, 87–94.

Brown, C., Laland, K., 2001. Social learning and life skills training for hatchery reared fish. J. Fish Biol. 59, 471–493.

Brunberg, E., Wallenbeck, A., Keeling, L.J., 2011. Tail biting in fattening pigs: associations between frequency of tail biting and other abnormal behaviours. Appl. Anim. Behav. Sci. 133, 18–25.

Bruni, A., Quinton, V.M., Widowski, T.M., 2008. The effect of feed restriction on belly nosing behaviour in weaned piglets. Appl. Anim. Behav. Sci. 110, 203–215.

Bulens, A., Renders, L., Van Beirendonck, S., van Thielen, J., Driessen, B., 2014. An exploratory study on the effects of a straw dispenser in farrowing crates. J. Vet. Behav.-Clin. Appl. Res. 9, 83–89.

Bulens, A., Biesemans, C., Van Beirendonck, S., van Thielen, J., Driessen, B., 2016. The effect of a straw dispenser on behavior and lesions in weanling pigs. J. Vet. Behav.-Clin. Appl. Res. 12, 49–53.

Burke, H.M., Davis, M.C., Otte, C., Mohr, D.C., 2005. Depression and cortisol responses to psychological stress: a meta-analysis. Psychoneuroendochrinology 30, 846–856.

Chaloupková, H., Illmann, G., Neuhauserová, K., Tomanek, M., Valis, L., 2007a. Preweaning housing effects on behavior and physiological measures in pigs during the suckling and fattening periods. J. Anim. Sci. 85, 1741–1749.

Chaloupková, H., Illmann, G., Bartoš, L., Špinka, M., 2007b. The effect of pre-weaning housing on the play and agonistic behaviour of domestic pigs. Appl. Anim. Behav. Sci. 103, 25–34.

Colson, V., Martin, E., Orgeur, P., Prunier, A., 2012. Influence of housing and social changes on growth, behaviour and cortisol in piglets at weaning. Physiol. Behav. 107, 59–64.

Cox, L.N., Cooper, J.J., 2001. Observations on the pre- and post-weaning behaviour of piglets reared in commercial indoor and outdoor environments. Anim. Sci. 72, 75–86.

Day, J.E.L., Burfoot, A., Docking, C.M., Whittaker, X., Spoolder, H.A.M., Edwards, S.A., 2002. The effects of prior experience of straw and the level of straw provision on the behaviour of growing pigs. Appl. Anim. Behav. Sci. 76, 189–202.

D'Eath, R.B., 2005. Socialising piglets before weaning improves social hierarchy formation when pigs are mixed post-weaning. Appl. Anim. Behav. Sci. 93, 199–211.

D'Eath, R.B., Arnott, G., Turner, S.P., Jensen, T., Lahrmann, H.P., Busch, M.E., Niemi, J.K., Lawernce, A.B., Sandøe, P., 2014. Injurious tail biting in pigs: how can it be controlled in existing systems without tail docking? Animal 8, 1479–1497.

DeBoer, S.P., Garner, J.P., McCain, R.R., Lay Jr., D.C., Eicher, S.D., Marchant-Forde, J.N., 2015. An initial investigation into the effects of isolation and enrichment on the welfare of laboratory pigs housed in the PigTurn (R) system, assessed using tear staining, behaviour, physiology and haematology. Anim. Welfare 24, 15–27.

de Jonge, F.H., Bokkers, E.A.M., Schouten, W.G.P., Helmond, F.A., 1996. Rearing piglets in a poor environment: developmental aspects of social stress in pigs. Physiol. Behav. 60, 389–396.

de Jonge, F.H., Boleij, H., Baars, A.M., Dudink, S., Spruijt, B.M., 2008. Music during playtime: using context conditioning as a tool to improve welfare in piglets. Appl. Anim. Behav. Sci. 115, 138–148.

de Kloet, E.R., Sibug, R.M., Helmerhorst, F.M., Schmidt, M., 2005. Stress, genes and the mechanism of programming the brain for later life. Neurosci. Biobehav. Rev. 29, 271–281.

de Oliveira, D., Paranhos da Costa, M.J.R., Zupan, M., Rehn, T., Keeling, L.J., 2015. Early human handling in non-weaned piglets: effects on behaviour and body weight. Appl. Anim. Behav. Sci. 164, 56–63.

De Paula Vieira, A.D., de Passillé, A.M., Weary, D.M., 2012. Effects of the early social environment on behavioral responses of dairy calves to novel events. J. Dairy Sci. 95, 5149–5155.

Docking, C.M., van de Weerd, H.A., Day, J.E.L., Edwards, S.A., 2008. The influence of age on the use of potential enrichment objects and synchronisation of behaviour of pigs. Appl. Anim. Behav. Sci. 110, 244–257.

Douglas, S.L., Edwards, S.A., Kyriazakis, I., 2014. Management strategies to improve the performance of low birth weight pigs to weaning and their long term consequences. J. Anim. Sci. 92, 2280−2288.
Dudink, S., Simonse, H., Marks, I., de Jonge, F.H., Spruijt, B.M., 2006. Announcing the arrival of enrichment increases play behaviour and reduces weaning-stress-induced behaviours of piglets directly after weaning. Appl. Anim. Behav. Sci. 101, 86−101.
Ernst, K., Tuchscherer, M., Kanitz, E., Puppe, B., Manteuffel, G., 2006. Effects of attention and rewarded activity on immune parameters and wound healing in pigs. Physiol. Behav. 89, 448−456.
Fernandez, V., Fernandez, B., Adaro, L., 2003. Early polysensorial enrichment: specific experience-induced structural changes in the parieto-occipital cortex of the rat. Growth Dev. Aging 67, 3−10.
Fraser, D., 1980. A review of the behavioural mechanism of milk ejection of the domestic pig. Appl. Anim. Behav. Sci. 6, 247−255.
Fraser, D., Milligan, B.N., Pajor, E.A., Phillips, P., Taylor, A.A., Weary, D.M., 1998. Behavioral perspectives on weaning in domestic pigs. In: Wiseman, J., Varley, M.A., Chadwick, J.P. (Eds.), Progress in Pig Science. Nottingham University Press, Nottingham, pp. 121−140.
Freedman, D.G., King, J.A., Elliot, O., 1961. Critical period in the social development of dogs. Science 133, 1016−1017.
Giroux, S., Robert, S., Martineau, G.P., 2000. The effects of cross-fostering on growth rate and post-weaning behavior of segregated early-weaned piglets. Can. J. Anim. Sci. 80, 533−538.
Gonyou, H.W., Beltranena, E., Whittington, D.L., Patience, J.F., 1998. The behaviour of pigs weaned at 12 and 21 days of age from weaning to market. Can. J. Anim. Sci. 78, 517−523.
Guy, J.H., Bums, S.E., Barker, J.M., Edwards, S.A., 2009. Reducing post-mixing aggression and skin lesions in weaned pigs by application of a synthetic maternal pheromone. Anim. Welfare 18, 249−255.
Harley, S., Boyle, L.A., O'Connell, N.E., More, S.J., Teixeira, D.L., Hanlon, A., 2014. Docking the value of pigmeat? Prevalence and financial implications of welfare lesions in Irish slaughter pigs. Anim. Welfare 23, 275−285.
Harlow, H.F., 1965. Total social isolation−effects on macaque monkey behaviour. Science 148, 666.
Hemsworth, P.H., Barnett, J.L., 1992. The effects of early contact with humans on the subsequent level of fear of humans in pigs. Appl. Anim. Behav. Sci. 35, 83−90.
Hemsworth, P.H., Coleman, G.J., 2011. Human−Livestock Interactions: The Stockperson and the Productivity and Welfare of Intensively Farmed Animals, vol. 2. CAB International, Oxford, UK.
Hemsworth, P.H., Barnett, J.L., Hansen, C., Gonyou, H.W., 1986. The influence of early contact with humans on subsequent behavioural response of pigs to humans. Appl. Anim. Behav. Sci. 15, 55−63.
Hill, J.D., McGlone, J.J., Fullwood, S.D., Miller, M.F., 1998. Environmental enrichment influences on pig behavior, performance and meat quality. Appl. Anim. Behav. Sci. 57, 51−68.
Hohenshell, L.M., Cunnick, J.E., Ford, S.P., Kattesh, H.G., Zimmermam, D.R., Wilson, M.E., Matteri, R.L., Carroll, J.A., Lay, D.C., 2000. Few differences found between early- and late-weaned pigs raised in the same environment. J. Anim. Sci. 78, 38−49.

Holmes, A., Le Guisquet, A.M., Vogel, E., Millstein, R.A., Leman, S., Belzung, C., 2005. Early life genetic, epigenetic and environmental factors shaping emotionality in rodents. Neurosci. Biobehav. Rev. 29, 1335–1346.

Horrell, R.I., Bennett, J.M.T., 1981. Disruption of teat preferences and retardation of growth following cross-fostering of 1-week-old pigs. Anim. Prod. 33, 99–106.

Horrell, I., Hodgson, J., 1992. The bases of sow-piglet identification. 2. Cues used by piglets to identify their dam and home pen. Appl. Anim. Behav. Sci. 33, 329–343.

Hötzel, M.J., Machado, L.C.P., Wolf, F.M., Dalla Costa, O.A., 2004. Behaviour of sows and piglets reared in intensive outdoor or indoor systems. Appl. Anim. Behav. Sci. 86, 27–39.

Hötzel, M.J., de Souza, G.P.P., Dalla Costa, O.A., Machado, L.C.P., 2011. Disentangling the effects of weaning stressors on piglets' behaviour and feed intake: changing the housing and social environment. Appl. Anim. Behav. Sci. 135, 44–50.

Huntingford, F.A., 2004. Implications of domestication and rearing conditions for the behaviour of cultivated fishes. J. Fish Biol. 65, 122–142.

Iacobucci, P., Colonnello, V., D'Antuono, L., Cloutier, S., Newberry, R.C., 2015. Piglets call for maternal attention: vocal behaviour in *Sus scrofa* domesticus is modulated by mother's proximity. Appl. Anim. Behav. Sci. 171, 88–93.

Iso, H., Simoda, S., Matsuyama, T., 2007. Environmental change during postnatal development alters behaviour, cognitions and neurogenesis of mice. Behav. Brain Res. 179, 90–98.

Janczak, A.M., Riber, A.B., 2015. Review of rearing-related factors affecting the welfare of laying hens. Poult. Sci. 94, 1454–1469.

Jarvis, S., Moinard, C., Robson, S.K., Sumner, B.E.H., Douglas, A.J., Seckl, J.R., Russell, J. A., Lawrence, A.B., 2008. Effects of weaning age on the behavioural and neuroendocrine development of piglets. Appl. Anim. Behav. Sci. 110, 166–181.

Kanitz, E., Tuchscherer, M., Puppe, B., Tuchscherer, A., Stabenow, B., 2004. Consequences of repeated early isolation in domestic piglets (*Sus scrofa*) on their behavioural, neuroendocrine, and immunological responses. Brain Behav. Immunol. 18, 35–45.

Kanitz, E., Hameister, T., Tuchscherer, M., Tuchscherer, A., Puppe, B., 2014. Social support attenuates the adverse consequences of social deprivation stress in domestic piglets. Horm. Behav. 65, 203–210.

Knudsen, E.I., 2004. Sensitive periods in the development of the brain and behaviour. J. Cogn. Neurosci. 16, 1412–1425.

Koopmans, S.J., Ruis, M., Dekker, R., Korte, M., 2009. Surplus dietary tryptophan inhibits stress hormone kinetics and induces insulin resistance in pigs. Physiol. Behav. 98 (4), 402–410.

Krause, E.T., Naguib, M., Trillmich, F., Schrader, L., 2006. The effects of short term enrichment on learning in chickens from a laying strain (*Gallus gallus* domesticus). Appl. Anim. Behav. Sci. 101, 318–327.

Kruska, D.C.T., 2005. On the evolutionary significance of encephalization in some eutherian mammals: effects of adaptive radiation, domestication, and feralization. Brain Behav. Evol. 65, 73–108.

Kutzer, T., Bünger, B., Kjaer, J.B., Schrader, L., 2009. Effects of early contact between non-littermate piglets and of the complexity of farrowing conditions on social behaviour and weight gain. Appl. Anim. Behav. Sci. 121, 16–24.

Larsen, M.L.V., Pedersen, L.J., 2015. Does light attract piglets to the creep area? Animal 9, 1032–1037.

Levine, S., 2005. Developmental determinants of sensitivity and resistance to stress. Psychoneuroendocrinology 30, 939–946.

Lewis, E., Boyle, L.A., O'Doherty, J.V., Lynch, P.B., Brophy, P., 2006. The effect of providing shredded paper or ropes to piglets in farrowing crates on their behaviour and health and the behaviour and health of their dams. Appl. Anim. Behav. Sci. 96, 1–17.

Li, Y., Gonyou, H.W., 2002. Analysis of belly nosing and associated behaviour among pigs weaned at 12–14 days of age. Appl. Anim. Behav. Sci. 77, 285–294.

Liu, D., Diorio, J., Tannenbaum, B., Caldji, C., Francis, D., Freedman, A., Sharma, S., Pearson, D., Plotsky, P.M., Meaney, M.J., 1997. Maternal care, hippocampal glucocorticoid receptors, and hypothalamic-pituitary-adrenal responses to stress. Science 277, 1659–1662.

Luchetti, A., Oddi, D., Lampis, V., Centofante, E., Felsani, A., Battaglia, M., D'Amato, F.R., 2015. Early handling and repeated cross-fostering have opposite effect on mouse emotionality. Front. Behav. Neurosci. 9, 93.

Martin, J.E., Ison, S.H., Baxter, E.M., 2015. The influence of neonatal environment on piglet play behaviour and post-weaning social and cognitive development. Appl. Anim. Behav. Sci. 163, 69–79.

McCune, S., 1995. The impact of paternity and early socialisation on the development of cats' behaviour to people and novel objects. Appl. Anim. Behav. Sci. 45, 109–124.

Melotti, L., Oostindjer, M., Bolhuis, J.E., Held, S., Mendl, M., 2011. Coping personality type and environmental enrichment affect aggression at weaning in pigs. Appl. Anim. Behav. Sci. 133, 144–153.

Miniats, O.P., Jol, D., 1978. Gnotobiotic pigs–derivation and rearing. Can. J. Comp. Med. 42, 428–437.

Moinard, C., Mendl, M., Nicol, C.J., Green, L.E., 2003. A case control study of on-farm risk factors for tail biting in pigs. Appl. Anim. Behav. Sci. 81, 333–355.

Morgan, T., Pluske, J., Miller, D., Collins, T., Barnes, A.L., Wemelsfelder, F., Fleming, P.A., 2014. Socialising piglets in lactation positively affects their post-weaning behaviour. Appl. Anim. Behav. Sci. 158, 23–33.

Muns, R., Rault, J.-L., Hemsworth, P., 2015. Positive human contact on the first day of life alters the piglet's behavioural response to humans and husbandry practices. Physiol. Behav. 151, 162–167.

Munsterhjelm, C., Peltoniemi, O.A.T., Heinonen, M., Halli, O., Karhapaa, M., Valros, A., 2009. Experience of moderate bedding affects behaviour of growing pigs. Appl. Anim. Behav. Sci. 118, 42–53.

Munsterhjelm, C., Valros, A., Heinonen, M., Halli, O., Sijander-Rasi, H., Peltoniemi, O.A.T., 2010. Environmental enrichment in early life affects cortisol patterns in growing pigs. Animal 4, 242–249.

Nakamura, K., Tanaka, T., Nishida, K., Uetake, K., 2011. Behavioral indexes of piglet welfare: comparison of indoor and outdoor housing systems. Anim. Sci. J. 82, 161–168.

Newberry, R.C., 1995. Environmental enrichment: increasing the biological relevance of captive environments. Appl. Anim. Behav. Sci. 44, 229–243.

Newberry, R.C., Wood-Gush, D.G.M., 1986. Social relationships of piglets in a semi-natural environment. Anim. Behav. 34, 1311–1318.

Nielsen, B.L., Jezierski, T., Bolhuis, J.E., Amo, L., Rosell, F., Oostindjer, M., Christensen, J. W., McKeegan, D., Wells, D.L., Hepper, P., 2015. Olfaction: an overlooked sensory modality in applied ethology and animal welfare. Front. Vet. Sci. 2, 69.

Nowicki, J., Swierkosz, S., Tuz, R., Schwarz, T., 2015. The influence of aromatized environmental enrichment objects with changeable aromas on the behaviour of weaned piglets. Vet. Arh. 85, 425–435.

Noyes, L., 1976. A behavioural comparison of gnotobiotic with normal neonate pigs, indicating stress in the former. Appl. Anim. Ethol. 2, 113–121.
O'Connell, N.E., Beattie, V.E., 1999. Influence of environmental enrichment on aggressive behaviour and dominance relationships in growing pigs. Anim. Welfare 8, 269–279.
O'Connell, N.E., Beattie, V.E., Sneddon, I.A., Breuer, K., Mercer, J.T., Rance, K.A., Sutcliffe, M.E.M., Edwards, S.A., 2005. Influence of individual predisposition, maternal experience and lactation environment on the responses of pigs to weaning at two different ages. Appl. Anim. Behav. Sci. 90, 219–232.
Oostindjer, M., Bolhuis, J.E., Mendl, M., Held, S., Gerrits, W., van den Brand, H., Kemp, B., 2010. Effects of environmental enrichment and loose housing of lactating sows on piglet performance before and after weaning. J. Anim. Sci. 88, 3554–3562.
Oostindjer, M., van den Brand, H., Kemp, B., Bolhuis, J.E., 2011. Effects of environmental enrichment and loose housing of lactating sows on piglet behaviour before and after weaning. Appl. Anim. Behav. Sci. 134, 31–41.
Oostindjer, M., Kemp, B., van den Brand, H., Bolhuis, J.E., 2014. Facilitating 'learning from mom how to eat like a pig' to improve welfare of piglets around weaning. Appl. Anim. Behav. Sci. 160, 19–30.
Pascual, R., Figueroa, H., 1996. Effects of preweaning sensorimotor stimulation on behavioral and neuronal development in motor and visual cortex of the rat. Biol. Neonate 69, 399–404.
Petersen, V., Simonsen, H.B., Lawson, L.G., 1995. The effect of environmental stimulation on the development of behaviour in pigs. Appl. Anim. Behav. Sci. 45, 215–224.
Price, E.O., Hutson, G.D., Price, M.I., Borgwardt, R., 1994. Fostering in swine as affected by age of offspring. J. Anim. Sci. 72, 1697–1701.
Pryce, C.R., 2008. Postnatal ontogeny of expression of the corticosteroid receptor genes in mammalian brains: inter-species and intra-species differences. Brain Res. Rev. 57, 596–605.
Pryce, C.R., Ruedi-Bettschen, D., Dettling, A.C., Weston, A., Russig, H., Ferger, B., Feldon, J., 2005. Long-term effects of early-life environmental manipulations in rodents and primates: potential animal models in depression research. Neurosci. Biobehav. Rev. 29, 649–674.
Rodenburg, T.B., 2014. The role of genes, epigenetics and ontogeny in behavioural development. Appl. Anim. Behav. Sci. 157, 8–13.
Roldan-Santiago, P., Trujillo-Ortega, M., Borderas-Tordesillas, F., Martinez-Rodriguez, R., Mora-Medina, P., Flores-Peinado, S., Sanchez-Hernandez, M., Garcia-Herrera, R., Gonzalez-Lozano, M., Mota-Rojas, D., et al., 2015. Physiometabolic responses to road transport in weaned piglets for a short period and the effects of straw bedding. Anim. Sci. J. 86, 563–571.
Rosenzweig, M.R., Bennett, E.L., 1996. Psychobiology of plasticity: effects of training and experience on brain and behaviour. Behav. Brain Res. 78, 57–65.
Rydhmer, L., Hansson, M., Lundstrom, K., Brunius, C., Andersson, K., 2013. Welfare of entire male pigs is improved by socialising piglets and keeping intact groups until slaughter. Animal 7, 1532–1541.
Rzezniczek, M., Gygax, L., Wechsler, B., Weber, R., 2015. Comparison of the behaviour of piglets raised in an artificial rearing system or reared by the sow. Appl. Anim. Behav. Sci. 165, 57–65.
Salmon, E.L.R., Edwards, S.A., 2007. Effects of housing system and litter grouping on performance and physiological maturity in entire boars and gilts. Proc. Br. Soc. Anim. Sci. 81.

Schmidt, M., Enthoven, L., van der Mark, M., Levine, S., de Kloet, E.R., Oitzl, M.S., 2003. The postnatal development of the hypothalamic–pituitary–adrenal axis in the mouse. Int. J. Dev. Neurosci. 21, 125–132.

Schmidt, M.V., 2010. Molecular mechanisms of early life stress—lessons from mouse models. Neurosci. Biobehav. Rev. 34, 845–852.

Schouten, W.G.P., 1986. Rearing Conditions and Behaviour in Pigs. Ph.D. Thesis. Wageningen Agricultural University, The Netherlands.

Siegford, J.M., Rucker, G., Zanella, A.J., 2008. Effects of pre-weaning exposure to a maze on stress responses in pigs at weaning and on subsequent performance in spatial and fear-related tests. Appl. Anim. Behav. Sci. 110, 189–202.

Simpson, J., Kelly, J.P., 2011. The impact of environmental enrichment in laboratory rats—behavioural and neurochemical aspects. Behav. Brain Res. 222 (1), 246–264.

Skok, J., Prevolnik, M., Urek, T., Mesarec, N., Škorjanc, D., 2014. Behavioural patterns established during suckling reappear when piglets are forced to form a new dominance hierarchy. Appl. Anim. Behav. Sci. 161, 42–50.

Smulders, D., Hautekiet, V., Verbeke, G., Geers, R., 2008. Tail and ear biting lesions in pigs: an epidemiological study. Anim. Welfare 17, 61–69.

Sneddon, I.A., Beattie, V.E., Dunne, L., Neil, W., 2000. The effect of environmental enrichment on learning in pigs. Anim. Welfare 9, 373–383.

Snowdon, C.T., Teie, D., Savage, M., 2015. Cats prefer species-appropriate music. Appl. Anim. Behav. Sci. 166, 106–111.

Sommavilla, R., Hötzel, M.J., Dalla Costa, O.A., 2011. Piglets' weaning behavioural response is influenced by quality of human–animal interactions during suckling. Animal 5, 1426–1431.

Špinka, M., Illmann, G., Haman, J., Šimeček, P., Šilerová, J., 2011. Milk ejection solicitations and non-nutritive nursings: an honest signaling system of need in domestic pigs? Behav. Ecol. Sociobiol. 65, 1447–1457.

Statham, P., Green, L., Mendl, M., 2011. A longitudinal study of the effects of providing straw at different stages of life on tail-biting and other behaviour in commercially-housed pigs. Appl. Anim. Behav. Sci. 134, 100–108.

Stolba, A., Wood-Gush, D.G.M., 1989. The behaviour of pigs in a semi-natural environment. Anim. Prod. 48, 419–425.

Suomi, S.J., Collins, M.L., Harlow, H., 1973. Effects of permanent separation from mother on infant monkeys. Dev. Psychol. 9, 376–384.

Sutherland, M.A., 2015. Welfare implications of invasive piglet husbandry procedures, methods of alleviation and alternatives: a review. N. Z. Vet. J. 63, 52–57.

Tallet, C., Rakotomahandry, M., Herlemont, S., Prunier, A., 2016. Impact de la coupe de queue sur le comportement des porcelets allaités. In: Presented at 48èmes Journées de la Recherche Porcine en France, vol. 47, pp. 235–240.

Tallet, C., Brajon, C., Devillers, N., Lensink, J., 2017. Pig-human interactions: creating a positive perception of humans to ensure pig welfare. In: Špinka, M. (Ed.), Advances in Pig Welfare. Woodhead Publishing, Duxford, UK.

Taylor, N.R., Main, D.C.J., Mendl, M., Edwards, S.A., 2010. Tail-biting: A new perspective. Vet. J. 186, 137–147.

Telkänranta, H., Swan, K., Hirvonen, H., Valros, A., 2014. Chewable materials before weaning reduce tail biting in growing pigs. Appl. Anim. Behav. Sci. 157, 14–22.

Tosi, M.V., Hemsworth, P.H., 2002. Stockperson–husbandry interactions and animal welfare in the extensive livestock industries. In: Proceedings of the 36th Conference of the International Society for Applied Ethology, p. 129.

Trickett, S.L., Guy, J.H., Edwards, S.A., 2009. The role of novelty in environmental enrichment for the weaned pig. Appl. Anim. Behav. Sci. 116, 45–51.

Tuchscherer, M., Kanitz, E., Puppe, B., Tuchscherer, A., 2006. Early social isolation alters behavioral and physiological responses to an endotoxin challenge in piglets. Horm. Behav. 50, 753–761.

Ursinus, W.W., Wijnen, H.J., Bartels, A.C., Dijvesteijn, N., van Reenen, C.G., Bolhuis, J.E., 2014a. Damaging biting behaviors in intensively kept rearing gilts: the effect of jute sacks and relations with production characteristics. J. Anim. Sci. 92, 5193–5202.

Ursinus, W.W., Van Reenen, C.G., Kemp, B., Bolhuis, J.E., 2014b. Tail biting behaviour and tail damage in pigs and the relationship with general behaviour: predicting the inevitable? Appl. Anim. Behav. Sci. 156, 22–36.

Valros, A., 2017. Tail biting. In: Špinka, M. (Ed.), Advances in Pig Welfare. Woodhead Publishing, Duxford, UK.

Vanderhaeghe, C., Dewulf, J., Jourquin, J., De Kruif, A., Maes, D., 2011. Incidence and prevention of early parturition in sows. Reprod. Domestic Anim. 46, 428–433.

van de Weerd, H.A., Day, J.E.L., 2009. A review of environmental enrichment for pigs housed in intensive housing systems. Appl. Anim. Behav. Sci. 116, 1–20.

van de Weerd, H.A., Docking, C.M., Day, J.E.L., Edwards, S.A., 2005. The development of harmful social behaviour in pigs with intact tails and different enrichment backgrounds in two housing systems. Anim. Sci. 80, 289–298.

Vanheukelom, V., Driessen, B., Maenhout, D., Geers, R., 2011. Peat as environmental enrichment for piglets: the effect on behaviour, skin lesions and production results. Appl. Anim. Behav. Sci. 134, 42–47.

Vanheukelom, V., Driessen, B., Geers, R., 2012. The effects of environmental enrichment on the behaviour of suckling piglets and lactating sows: a review. Livest. Sci. 143, 116–131.

Vanhonacker, F., Verbeke, W., 2011. Consumer response to the possible use of a vaccine method to control boar taint v. physical piglet castration with anaesthesia: a quantitative study in four European countries. Animal 5, 1107–1118.

van Nieuwamerongen, S.E., Bolhuis, J.E., van der Peet-Schwering, C.M.C., Soede, N.M., 2014. A review of sow and piglet behaviour and performance in group housing systems for lactating sows. Animal 8, 448–460.

Varley, M.A., Maitland, A., Towle, A., 1986. Artificial rearing of piglets: the administration of two sources of immunoglobulins after birth. Anim. Prod. 43, 121–126.

Walton, K.D., Lieberman, D., Llinás, A., Begin, M., Llinás, R.R., 1992. Identification of a critical period for motor development in neonatal rats. Neuroscience 51, 763–767.

Wattanakul, W., Stewart, A.H., Edwards, S.A., English, P.R., 1997a. Effects of grouping piglets and changing sow location on suckling behaviour and performance. Appl. Anim. Behav. Sci. 55, 21–35.

Wattanakul, W., Sinclair, A.G., Stewart, A.H., Edwards, S.A., English, P.R., 1997b. Performance and behaviour of lactating sows and piglets in crate and multisuckling systems: a study involving European White and Manor Meishan genotypes. Anim. Sci. 64, 339–349.

Wattanakul, W., Edwards, S.A., Stewart, A.H., English, P.R., 1998. Effect of familiarity with the environment on the behaviour and performance response of sows and piglets to grouping during lactation. Appl. Anim. Behav. Sci. 61, 25–39.

Weary, D.M., Jasper, J., Hötzel, M.J., 2008. Understanding weaning distress. Appl. Anim. Behav. Sci. 110, 24–41.

Weaver, S.A., Ahern, F.X., Meaney, M.J., Schaefer, A.L., Dixon, W.T., 2000. Neonatal handling permanently alters hypothalamic−pituitary−adrenal axis function, behaviour, and body weight in boars. J. Endocrinol. 164, 349−359.

Widowski, T.M., Yuan, Y., Gardner, J.M., 2005. Effect of accommodating sucking and nosing on the behaviour of artificially reared piglets. Lab. Anim. 39, 240−250.

Worobec, E.K., Duncan, I.J.H., Widowski, T.M., 1999. The effects of weaning at 7, 14 and 28 days on piglet behaviour. Appl. Anim. Behav. Sci. 62, 173−182.

Yonezawa, T., Takahashi, A., Imai, S., Okitsu, A., Komiyama, S., Irimajiri, M., Matsuura, A., Yamazak, A., Hodate, K., 2012. Effects of outdoor housing of piglets on behavior, stress reaction and meat characteristics. Asian-Aust. J. Anim. Sci. 25, 886−894.

You, X.L., Li, Y.B., Zhang, M., Yan, H.Q., Zhao, R.Q., 2014. A survey of Chinese citizens' perceptions on farm animal welfare. PLoS One 9, e109177.

Zebunke, M., Langbein, J., Manteuffel, G., Puppe, B., 2011. Autonomic reactions indicating positive affect during acoustic reward learning in domestic pigs. Anim. Behav. 81, 481−489.

Zupan, M., Janczak, A.M., Framstad, T., Zanella, A.J., 2012. The effect of biting tails and having tails bitten in pigs. Physiol. Behav. 106, 638−644.

Tail biting

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5

5.1 Introduction

5.1.1 Tail biting

Tail biting is probably the most serious behaviour problem in pigs, occurring commonly in a wide range of modern pig production systems. During a bout of tail biting behaviour (hereafter referred to as 'tail biting') one pig takes the tail of another pig into its mouth, and bites it, usually causing the bitten pig to react by vocalizing or escaping. The possibly resulting damage (hereafter referred to as 'tail biting damage') can range from mild bite marks, with or without punctuation of the skin, to the tail being fully removed. In extreme cases, the tail biting continues, resulting in tissue damage beyond the tail, or even mortality of the bitten pigs. Mostly, however, tail biting damage occurs in milder forms, with severe tail biting damage, often defined as a clear bite marks, visible blood, or part of the tail missing (e.g., Valros et al., 2016), representing about 10%–25% of all bitten tails (Valros et al., 2004; Keeling et al., 2012). When comparing studies reporting the prevalence of tail biting damage, one needs to be very careful as definitions and scoring criteria differ greatly between studies. Studies report between 2% and 12% of severe tail biting damage in non-docked pigs and up to about 3% in docked pigs (reviewed by Valros and Heinonen, 2015). Tail biting damage is most commonly reported during the growing and fattening phases, but also occurs in rearing gilts (Bracke et al., 2013; Ursinus et al., 2014a) and even in pre-weaning piglets (Ursinus et al., 2014b). Tail biting damage is generally not reported to be a problem in adult sows.

5.1.2 Tail docking

Tail docking, which means surgically removing a part of the tail, is performed in order to reduce the risk for tail biting damage, and studies do indicate that tail docking can reduce the incidence of tail biting damage 2–4-fold, depending on the study setup, scoring method and the length of the remaining tail (reviewed by Valros and Heinonen, 2015). Tail docking is performed to a very high degree: over 90% of the pigs in EU have been estimated to be docked (EFSA, 2007), although routine tail docking is banned in the EU (Council Directive 2008/120/EC, Annex 1). The reason for docking being so common, although it is banned, is that the regulation allows tail docking if no other methods have been successful in reducing the tail biting damage incidence satisfactorily. A total ban has been enforced only in a few countries, including Finland, Sweden, Norway, and Switzerland (EFSA, 2007). However,

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discussions are ongoing on enforcing the ban more strictly within the EU. A recent EFSA opinion (2014) suggests, based on a large dataset from studies using the Welfare Quality protocol, with data from 242 intensive fattening farms in five countries that it is possible to house and manage undocked pigs in a way which does not increase the risk for tail biting damage. In many non-European countries, such as the United States and China, tail docking is performed routinely (Sutherland, 2015).

5.2 What motivates tail biting?

The motivational background of tail biting remains unclear. However, it appears to be connected to an increased stress level in the pigs (Zupan et al., 2012; Munsterhjelm et al., 2013a), and can be induced by a wide range of risk factors (EFSA, 2007, 2014), probably influencing a wide range of motivational systems, such as those regulating explorative behaviour, foraging, thermoregulation and social behaviour. Understanding the motivational background is made even more challenging by the fact that there appears to be different types of tail biting, as proposed by Taylor et al. (2010). The 'two-stage' type of tail biting, which starts as non-injurious tail-in-mouth (TIM) behaviour, and then escalates to actual biting, has been suggested to be due to a chronic, but moderate, level of stress or frustration. This type of tail biting can occur even when pigs are lying down, and does not appear to be related to aggressive behaviour. 'Two-stage' tail biting does not always result in very serious tail damage, and a single biter might be difficult to identify. The 'sudden-forceful' type of tail biting occurs in situations where a pig wants to gain access to a resource, such as feeding. In these cases, a pig might, in extreme cases, even remove the entire tail of another pig instantly, and the behaviour may or may not spread to other pigs in the pen. The third type of tail biting, as suggested by Taylor et al. (2010) is the 'obsessive' type, where a pig appears to have developed an obsession to biting other pigs. These obsessive tail biters are probably the most easy to identify on-farm, are often described by farmers as having a 'mad glance' in their eyes, and are often said to be small female pigs. In addition to the three tail biting types suggested by Taylor et al. (2010) I suggest that there might be a fourth type, which does not fit directly into the above: the suddenly occurring, epidemic-type behaviour. In these cases, an acute change in the environment, such as a feeding problem or a rapid change in temperature can cause a sudden outbreak of tail biting damage. The result may be serious, and the behaviour spreads like an epidemic, with the likelihood of further bites increasing for each bite observed in a pen (Niemi et al., 2011). The different types of tail biting behaviour are summarised in Table 5.1.

5.2.1 Why does tail docking reduce the risk for tail biting damage?

The reason for why tail docking is efficient in reducing the incidence of tail biting damage is still not fully understood. It has been suggested that a long tail is more attractive to pigs than a shorter one, possibly even more so due to the fact that a

Table 5.1 Different types of tail biting

Type of tail biting behaviour	Characteristic of tail biting behaviour	Type of resulting tail biting damage	Suggested causation	Examples of potential preventive measures
Two-stage[a]	Starts as non-damaging tail-in-mouth behaviour, but escalates to actual tail biting. Single biters may be difficult to identify	Mild to moderate tail biting damage in several pigs within a pen/pens	Chronic, moderate stress or frustration, due to, e.g., lack of manipulative material	Modifying the housing and management to better meet the needs of pigs, e.g., by adding more manipulative material
Sudden-forceful[a]	A pig suddenly, and often with great force, bites another pigs' tail in a situation of competition	Severe tail biting damage suddenly occurring in one or several pigs	Competition for resources, especially for feed	Reducing the risk for competition, by e.g., making sure all pigs can eat simultaneously
Obsessive[a]	A specific pig exhibits continuous tail biting of many other pigs in a pen, often going from one tail to the other during active periods	Mild to severe tail biting damage in several pigs within a pen. The biter may be the only pig with an undamaged tail in the pen	Individual characteristics of the tail biting pig, possibly due to mental changes due to, e.g., experiencing long-term challenges	Avoiding long-term challenges in pigs. Identifying problem pigs at an early stage and removing them from their home pen
Epidemic	Tail biting occurs suddenly in one or several pens, spreading quickly. Specific biters might be difficult to identify	Mild to severe tail biting damage in several pigs in one to several pens	Sudden, acute changes in the pigs' life, such as feeding disturbances, changes in the temperature	Managing the farm in a way that reduces the risk for sudden changes. This can include, e.g., alarms for feeding or ventilation system malfunction and frequent maintenance of on-farm technology

[a]These types were first suggested by Taylor et al. (2010).

fully intact, non-docked tail has a brush of hairs on the end. However, a recent study failed to show that pigs were more interested in intact than docked tails (Paoli et al., 2016). Also, tail tipping, which is a procedure where only the very end of the tail is docked, has not been proven to be very efficient in preventing tail biting damage, as compared to docking a more significant part of the tail. More, and more serious biting damage in occurred in tipped than docked tails (Sutherland et al., 2009; Scollo et al., 2016). Another suggestion is that the tail becomes more sensitive to manipulation due to the docking causing neural changes in the tip of the tail (Sutherland et al., 2009; Herskin et al., 2015). However, so far there are no studies to show that docked victims of tail biting would react more to tail manipulation than long-tailed victims (Paoli et al., 2016). Thus, it might simply be that a long tail is easier to bite, and to cause serious damage on, as it can be taken into the mouth and chewed on with the cheek teeth (Paoli et al., 2016). Data seem to support this, showing that the more of the tail that is docked, the more tail damage is prevented (Hunter et al., 2001; Thodberg et al., 2010).

5.3 Risk factors for tail biting: the pig

Studies focusing on identifying individual characteristics often divide phenotypes into groups based on their involvement in tail biting behaviour. Typically, pigs are referred to as biters (pigs that perform tail biting), receivers or victims (pigs than are bitten or have tail damage) and controls or neutrals (pigs that are neither bitten nor performing tail biting). Furthermore, in some studies, neutrals are further compared to control pigs in pens where no tail biting occurs. For clarity, in the below sections, irrespective of how the original study named the different categories, the different groups or phenotypes are referred to as 'performers' (pigs performing tail biting or TIM), 'receivers' (pigs receiving tail biting or TIM, or pigs with recorded tail damage), 'neutrals' (pigs in tail biting pens, which do not receive or perform tail biting or TIM) and 'controls' (pigs in pens with no tail biting). In some studies, performers and receivers are not clearly separate phenotypes, but may have elements of both, although being predominantly one or the other. This phenotypic overlap was shown in the study by Zonderland et al. (2011a), where almost all pigs in pens with signs of tail biting damage were involved as performers or receivers at some stage of a period from 6 days before to 6 days after the first tail biting damage was recorded. In some pens of this study, one could identify one or a few pronounced performers, but not in all pens, and this was also true for the receivers.

5.3.1 Genetics and breeding

The evidence for breed effect on becoming a performer or receiver of tail biting is, so far, not conclusive. Tail biting damage was more prevalent in Yorkshire pigs in the study by Sinisalo et al. (2012) than in Landrace pigs, also supported by the study by Westin (2003), where Yorkshire pigs had the most tail biting damage, followed by Landrace and Hampshire pigs. There are very few studies on breed differences in the risk of becoming a performer of tail biting, with most studies showing no breed differences. Sinisalo et al. (2012) showed that most identified performers were Landrace, as compared to Yorkshire, and Westin (2003) also showed a larger percentage of performers being Landrace than Yorkshire or Hampshire. Both these studies were, however, based on rather small samples. Also Breuer et al. (2005) reported a tendency for a higher percentage of tail biting performers in Landrace than Yorkshire pigs. Further, Breuer et al. (2003) showed that Duroc pigs interacted more with a rope in a tail-chew test than Landrace and Yorkshire pigs, and that Duroc pigs also performed more biting towards other pigs than the other breeds. The tail-chew test was, however, not found to be a good predictive test of tail biting.

There is, so far little information on the genetic background of tail biting. Breuer et al. (2005) showed some indication of heritability, with tail biting being significantly, although not very strongly, heritable in the Landrace pigs. There appears to be a genetic association between tail biting and growth and leanness: Breuer et al. (2005) showed that tail biting appears to be genetically related to a higher lean growth, supported by Ursinus et al. (2014a) who showed that rearing gilts that performed tail biting were phenotypically heavier and grew faster than non-biting gilts and also had a higher genetic potential for litter size and growth, while receivers had a lower potential for back fat. Further, pigs with tail biting damage were shown to have a lower genetic growth potential than pigs without tail biting damage (Sinisalo et al., 2012). Wilson et al. (2012) attempted to identify chromosomal locations associated with tail biting, and found some loci to be associated to being a performer or receiver of tail biting. The identified loci did not, however, allow for conclusions on the genetic background to tail biting. Wilson et al. (2012) also reported a moderate genetic association between being a performer and a receiver of tail biting, which is interesting in the light of studies on gene expression: Brunberg et al. (2013a,b) found some interesting gene expression differences between pigs with different phenotypes regarding tail biting. The authors showed that neutral pigs differ more in their gene expression from performers and receivers than the two last-mentioned groups do from each other. The fact that these neutral pigs also differed similarly from control pigs in a non-tail-biting pen suggests that they might represent a tail-biting-resistant genotype, instead of exhibiting gene expression differences merely as a result of the current environment. Interestingly, and supporting the studies on genetic associations between tail biting and leanness, one of the observed differences in gene expression was related to leanness. Also genes related to social behaviour, indicating less piglet-directed interest in neutral pigs, and to novelty seeking and the dopamine system were differently expressed in the neutral pigs.

Recent studies have shown that breeding for indirect effects, such as the effect of the individual on the growth of its social peers, might have a positive effect on the welfare of a group, including a reduction of the level of negative social behaviour, such as tail biting. Camerlink et al. (2015) showed that when pigs had been selected for high indirect effects on growth, they exhibited less tail and ear biting, as well as a reduced level of manipulation of enrichment.

5.3.2 Gender

There are several studies showing a higher prevalence of tail biting damage in male pigs than in female pigs (Valros et al., 2004; Kritas and Morrison, 2004, 2007), while Sinisalo et al. (2012), did not find a gender difference in tail biting damage. Anecdotally, farmers often indicate that performers tend to be small females, even though this has not been proven in scientific studies. The reason why females are thought to be more prone to tail biting than castrated males is that they are more active than males, and when reaching puberty at the end of the growing period, they might become more interested in the ano-genital area of other pigs in general (Schrøder-Petersen and Simonsen, 2001). However, Zonderland et al. (2010) found that females had a higher propensity to bite already during the first month after weaning, as compared to intact male piglets, and a similar finding was reported for females single-sex groups regarding TIM (Schrøder-Peterson, 2004) when they were around 40−50 kg. On the contrary, Zonderland et al. (2011b) failed to report a difference in gender distribution among performers, while Sinisalo et al. (2012) reported that intact boars were diagnosed as performers by farm staff more often than females or barrows, in a small data including 33 performers of tail biting.

Zonderland et al. (2010) studied the effect of gender composition of groups and found that all-female groups had an increased tail biting development compared to pigs in mixed groups or all-male groups. Kritas and Morrison (2007) showed that there was a positive correlation between the number of barrows with tail biting damage and the percentage of gilts in mixed gender groups. They suggested that this might mean that gilts are more prone to bite barrows than other gilts in mixed pens.

5.3.3 Health

The general health status of the farm has been suggested to be related to the risk of tail biting (Edwards, 2011), and taking care of animal health has also been assessed as very important for preventing tail biting damage by Finnish farmers (Valros et al., 2016). Moinard et al. (2003) showed an increased risk for tail biting damage on farms with respiratory diseases, rectal prolapses and a high level of piglet post-weaning mortality. Marques et al. (2012) and Niemi et al. (2011) showed that there is a connection between tail biting and locomotory problems, and Munsterhjelm et al. (2013b) showed that pigs with acute tail damage had an increased prevalence of respiratory infection, as compared to pigs with no tail damage. A recent study could link certain cytokines to changes in social behaviour, which have previously been associated to tail biting. Further, the study showed that the health status of the pig appears to influence both the received and performed social behaviour toward pen-mates (Munsterhjelm et al 2017). However, most of these studies fail to conclude anything about the cause and effect of the relationship. Niemi et al. (2011) did show that pigs diagnosed with lameness had an increased risk for later being diagnosed with tail biting damage than non-lame pigs. Further, D’Eath et al. (2014) summarised two studies connecting anthelmintic treatment and vaccination to reduced risk for tail biting damage.

5.3.4 Size and growth of pigs

The quality of piglets, including health and an even growth, was rated as an important measure for preventing tail biting by Finnish producers in the study by Valros et al. (2016). As previously mentioned, it has been suggested that performers of tail biting are smaller than other pigs (Schrøder-Petersen and Simonsen, 2001), which could be due to reduced feed intake or a problem related to nutrient absorption, causing an increased motivation for foraging and exploration. Van de Weerd et al. (2005) showed that obsessive biters appeared to be smaller than average pigs. In addition, Munsterhjelm et al. (2016a) recently showed that pigs that were to become performers of TIM after weaning were born slightly smaller than pigs that were to become receivers of the behaviour. However, there was no size difference left at weaning, and no difference between these phenotypes in growth. Sinisalo et al. (2012) reported that pigs that were to be diagnosed as performers at a later stage were lighter than other pigs when arriving at the fattening unit. However, Munsterhjelm et al. (2013b) found no difference between weight of performers of tail biting and other phenotypes, when weight was assessed during the outbreak of tail biting, and also Zonderland et al. (2011b) failed to find a significant size difference between performers of tail biting and neutral pigs, even though the performers were numerically smaller. Instead, Zonderland et al. (2011b) reported that receivers of tail biting were larger than neutrals and performers before the outbreak of biting started. Palander et al. (2013) assessed if performers show signs of decreased nutrient intake by studying intestinal morphology and blood metabolites, but found no such indications.

5.3.5 Behavioural phenotypes

It is not clear if being a tail biter is an individually stable trait or not. Munsterhjelm et al. (2016a) reported behavioural differences between phenotypes already before tail manipulation had started: just after weaning, and before any TIM behaviour had been recorded, future performers were more active than receivers, and also performed more environmental exploration. This is similar to the results by Zonderland et al. (2011b) showing that future performers of tail biting manipulate both other pigs and enrichment devices more during the days before an outbreak than future neutral or receiver pigs. However, on the contrary, Ursinus et al. (2014b) failed to report tail biting as such to be a consistent behaviour, as there was no increased risk of tail biting in pigs that had been performers at previous stages of the production period. Instead, Ursinus et al. (2014b) found that being a receiver of tail biting was more consistent over time than being a tail biter.

It appears that being a performer of tail biting is related to a more general behavioural phenotype. There are a few studies indicating that tail biting is part of a more general individual characteristic. Brunberg et al. (2011) showed that there was a link between a high level of individual tail biting behaviour and high levels of TIM behaviour, as well as of other biting behaviour (ear biting and bar biting). They concluded that pigs that perform a high level of tail biting are also more prone to other biting-type abnormal behaviours. In addition, the same study showed that pigs that received a high level of tail bites also receive a higher amount of other types of abnormal behaviour than other pigs. Further, Bracke and Ettema (2014) showed that pigs from pens where either tail or flank biting damage was present were more interested in manipulating a novel rope, compared to control pens without injured pigs. This seems to indicate that tail biting and other injurious behaviours, such as flank biting, may share a related motivational basis.

5.3.5.1 How does a pig stay neutral?

As indicated in the chapter on genetic backgrounds by Turner et al. (Chapter 14: Breeding for pig welfare: opportunities and challenges), an interesting phenotypic group of pigs are the neutral pigs, i.e., those pigs that live in pens with tail biting, but do neither perform nor receive tail bites. Brunberg et al. (2013a) showed that, in addition to differing in their gene expression pattern, these pigs also differed in their behaviour from control pigs in pens without tail biting. Munsterhjelm et al. (2016a) reported that pigs that remained neutral throughout their study were socially more passive at age 9 weeks, when TIM behaviour had emerged in the pen, than other phenotypes. Further, Palander et al. (2013) found that neutral pigs exhibited decreased jejunal villus height, as compared with control pigs in pens with no tail biting. A reduction of villus height can occur as a result of stress, or due to malnutrition, and may result in a decreased capacity to absorb nutrients. These pigs also showed a reduced level of certain minerals in the blood, namely calcium and phosphorus. However, the neutral pigs were not significantly, although numerically, smaller than the control pigs, indicating they had not suffered feed deprivation for a prolonged period. Based on these results, they suggested that a recent reduction in feed intake, may be due to the neutral pigs avoiding tail biting by staying away from the feeder, which is where a large amount of tail biting has occurred in some studies (Palander et al., 2012; Sutherland et al., 2009). Thus, these results further support the fact that there might be a specific phenotype associated with staying a non-biting, non-bitten pig in a tail biting pen.

5.3.6 Neurotransmission

Tail biting has been linked to changes in neurotransmission in a few recent studies: Ursinus et al. (2014c) showed that performers had a reduced level of blood platelet serotonin during the period of exhibited tail biting and Valros et al. (2015) showed an increased central serotonin metabolism in the prefrontal cortex in performers during an acute tail biting outbreak. The brain serotonin level in the latter study was connected to the level of its precursor, tryptophan, in blood. This, together with the lower blood platelet serotonin reported by Ursinus et al. (2014c) indicates that performer pigs may have an increased central use of serotonin during tail biting, and that under these circumstances tryptophan may become a limiting resource for the pigs. Martínez-Trejo et al. (2009) showed that ear and tail biting was decreased when piglets were given a higher level of tryptophan in the feed. Furthermore, both the serotogenic and the dopaminergic system appears to be influenced by biting in receivers of tail biting: receiver pigs were shown to have decreased blood platelet serotonin (Ursinus et al., 2014c), as well as increased central levels of both serotonin and dopamine metabolites in the limbic system and the striatum during an ongoing outbreak (Valros et al., 2015). The changes in the receivers may be due to the acute stress caused by being bitten. As the changes in serotonin metabolism occurred in the prefrontal cortex in performers, and in the striatum and limbic area in receivers, this suggests a different level of cognitive and emotional processing being involved in these differences between the two phenotypes (Valros et al., 2015).

5.4 Risk factors for tail biting: the environment

A high number of housing and management-related risk factors for tail biting have been identified in the scientific literature, illustrated by the diversity of the on-farm tail biting intervention tool HAT, which includes 83 risk factors (Taylor et al., 2012). There is a big variation between farms in their tail biting prevalence (Valros et al., 2004), indicating that on-farm factors do influence tail biting to a great extent. One of the difficulties in preventing tail biting is the fact that every farm is different, and it has therefore been proposed that prevention strategies need to be designed on a farm-specific level (EFSA, 2014). Taylor et al. (2012) showed that when applying the HAT tool, farms with very different basic systems (such as with or without straw bedding) could achieve similar risk levels for tail biting. This need for farm-specific intervention strategies was also indicated by the farmer response in the questionnaire study by Valros et al. (2016): for some preventive measures, farmers suggested opposite strategies for reducing the tail biting risk – such as several farmers saying that the feeding level needs to be over the recommendation, while another making it clear that over-feeding is an important risk factor.

Bracke (2008) and Bracke et al. (2012) have suggested a tilting bucket model for understanding the background for tail biting. The idea is that the 'bucket' representing the added risk of tail biting, stands on an uneven surface, and is tipped if it becomes too full. The bucket is filled up by risk factors belonging to different categories, including feeding, environment, climate, health and animal factors, and with boredom experienced by the pigs as a main factor on the bottom. When the level of risk factors in the bucket reach a certain threshold level, the bucket is tipped over and tail biting occurs.

Another way of trying to clarify the background of tail biting has been suggested by Valros (EAAP, 2015). This model includes elements from the bucket model, such as the risk factors adding up until they meet a threshold for tail biting to occur. We further suggest that environmental risk factors can be divided into chronic risk factors, and acute risk factors. The chronic risk factors are those housing and management routines being relatively standard on a farm and include factors such as floor type, space allowance, feeding system, and use of manipulable materials. Chronic risk factors are usually more predictable than acute risk factors, and are based on decisions throughout the process of planning and managing a farm. For example, by choosing to build a system with fully slatted floors, the producer increases the risk of tail biting on a chronic level. Acute risk factors, on the other hand, are more difficult to predict and prevent. These include sudden changes in the environment of the pig, such as changes in temperature or air quality, resulting from changes in outdoor climate, or interruptions of the normal feeding pattern due to feeder malfunction. These acute risk factors are difficult to study experimentally, and even epidemiologically, but are often reported anecdotally by farmers. As the acute risk factors are difficult to control, reducing the chronic risk factors provides a better long-term means to control the situation: even though every modern pig farm runs the risk of tail biting outbreaks, studies show that the risk can be significantly reduced by housing and management decisions (EFSA, 2007). The owner of the biggest pig farm in Finland, a piglet producing and weaner pig unit with 3500 sows, underlined the importance of planning the production system so that tail biting is prevented systematically. On a farm of this size, every-day management is difficult to control, and professional staff might not always be available (Heikkilä T., personal communication). This theoretical model is illustrated in Fig. 5.1, where Farm A represents a farm with a very low level of chronic risk factors and Farm D a farm with a very high level of chronic risk factors. Farm B and C are intermediate. On Farm D tail biting occurs as an ongoing problem, as merely the chronic risk factors add up to a stress level experienced by the pigs, which is above the threshold for tail biting. On Farm A, the housing and management is such that the chronic risk factor level is very low. Thus, even when a rather severe acute risk factor is introduced,

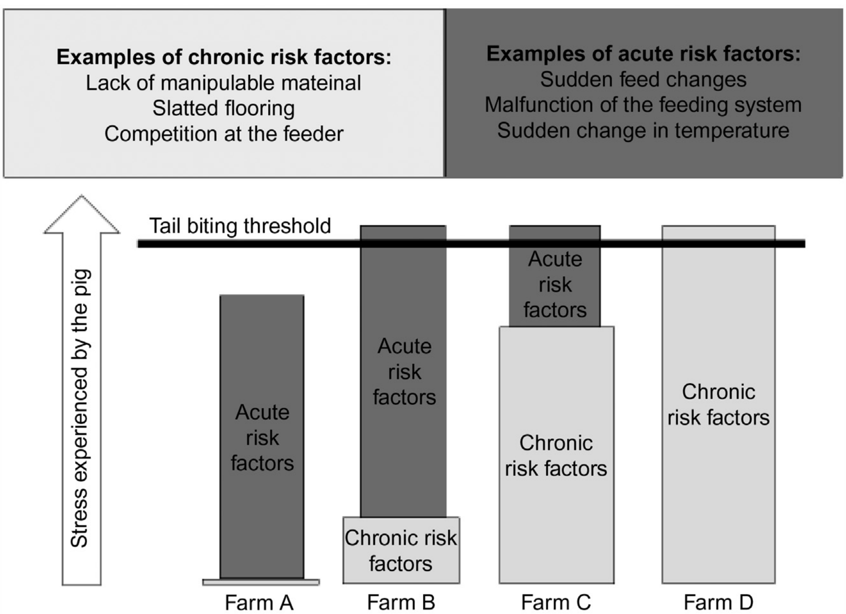

Figure 5.1 Theoretical model of the additive effect of chronic and acute risk factors for tail biting outbreaks.

tail biting might not occur. The same intensity of the acute risk factor, however, will cause tail biting to occur on the intermediate Farm B. Further, on Farm C, even a rather minor acute risk factor will be enough to cause tail biting.

5.4.1 Feeding

The role of feeding for prevention of tail biting has been underlined by producers (Valros et al., 2016). Feeding as a factor in the tail biting puzzle has also received more and more research attention in recent years, even though it was not previously rated very high by experts (EFSA, 2007).

5.4.1.1 Feed structure

Pellet feeding has been shown to increase the risk for tail biting (Hunter et al., 2001; Tetsuo et al., 2015), while Temple et al. (2012) and Palander (2016) showed an increased risk in connection to liquid feeding. These inconsistent results might be due to different feeding methods being used in the different countries, and to confounding effects, such as certain feed types being connected to certain feeding methods, as well as to feed components and quality. It has been suggested that the quality and contents of liquid feeds might be more variable than that of dry feed (Palander, 2016), and as discussed in the following paragraph, an even and correct feed content was rated as very important for preventing tail biting by farmers (Valros et al., 2016).

5.4.1.2 Feed content

Even though feed content has been repeatedly suggested as an important factor for tail biting, suggesting, e.g., the contents of energy, fibre, protein and minerals might affect the tail biting risk (Schrøder-Petersen and Simonsen, 2001; D'Eath et al., 2014; Valros et al., 2016), so far most studies have failed to show clear effects of feed composition, or of specific nutrients, on the risk of tail biting. As reported earlier in this chapter, and increased level of tryptophan was related to a reduced biting prevalence (Martinez-Trejo et al., 2009). Also, Palander (2016) found an increased tail biting risk when using purchased compound feeds, or when including whey or wheat in the diet of weaners.

5.4.1.3 Feeding methods

The way that feed is presented to the pigs appears to be a very important risk factor for tail biting. Studies indicate that competition for feed is a major risk factor, may be due to pigs, who naturally tend to synchronise their feeding, get frustrated when not gaining simultaneous access to feed, resulting in the 'sudden-forceful' type of tail biting (Taylor et al., 2010). The importance of feeding competition is also shown by the fact that a large amount of tail biting actually happens around the feeder: Sutherland et al. (2009) reported 30% of tail biting occurred at the feeder, and in the study by Palander et al. (2012), half of the tail biting occurred in a 1 m^2

area around a one-space feeder within a pen of a total of 12 m^2. In the latter study, however, most of the tail biting was rather mild, thus indicating that it might not have been predominately the 'sudden-forceful' type. An alternative explanation might be a generally increased feed-related frustration. In another study by Palander et al. (2013), pigs fed ad libitum, but with restricted feeder space, had a reduced level of essential amino acids in the blood, as well as changes in the intestinal wall structure indicative of feed restriction, as compared to pigs fed in meals from a long trough. The authors suggested that with the restricted feeder space, competition for food is increased, although it is freely available. The increased competition might cause some pigs to eat less, with the risk of increased feed-related frustration (Palander et al., 2013), which could be a risk factor for tail biting.

Producers in Finland, who are used to rearing long-tailed pigs, frequently underline the importance of long-trough-feeding, with enough space for all pigs to eat at the same time, as illustrated in Fig. 5.2, for reducing the tail biting risk. This was also shown in the study by Valros et al. (2016), where enough feeder space was ranked highest on the list of preventive measures. Hunter et al. (2001) reported that the use of double- or multi-space feeders, in comparison to single space feeders was correlated to a lower risk of tail biting and Moinard et al. (2003) showed that using a feeder system with more than five pigs per feeding space increased the risk for tail biting.

Feeding several times a day, as compared to twice a day, increased tail biting risk in the study by Palander (2016). Temple et al. 2012 also showed that an increase in the frequency of feeding from two to four times a day induced larger relative risk for tail biting. Palander (2016) concluded that this might be caused by

Figure 5.2 Long through feeding allows enough space for all pigs to eat at the same time. Note that the tail of last pig to the right is held down, which indicates some tail biting already occur in this pen
Source: Courtesy Mona Lilian Vestbjerg Larsen.

dividing the same amount of food into smaller meals, which might leave the pigs hungry after feeding, and might also increase the risk for total competition for feed.

5.4.2 Access to manipulable material

Use of manipulable materials is often considered the most important factor for reducing the risk of tail biting (EFSA, 2007), and is also the factor getting most research attention so far (D'Eath et al., 2014). Pigs have a need to manipulate and explore, and when this is not met, it can lead to undesired behaviours, such as tail biting (EFSA, 2014). However, the importance of manipulable materials as a way to reduce boredom in pigs, was not considered equally important by the Dutch producers in the study by Bracke et al. (2013), and producers have criticised researchers for focusing too much on manipulable materials, instead of looking at the tail biting problem more holistically (Benard et al., 2014). Even though Finnish producers scored the use of bedding-type materials as important for reducing the tail biting risk, this factor only ranked 13th on a list of 20 risk factors (Valros et al., 2016).

Here we only summarise some materials effective for reducing the tail biting risk, while further discussion on manipulable materials can be read in the chapters by Bracke (Chapter 6: Chains as proper enrichment for intensively-farmed pigs?) and Telkänranta and Sandra Edwards (Chapter 4: Lifetime consequences of the early physical and social environment of piglets).

According to a large dataset from Finland (EFSA, 2014), it appears that even small amounts of straw can reduce the risk of tail biting risk. Deep bedded systems might not even be the best solution, as suggested by Hunter et al. (2001), who showed that the probability of tail biting damage was lowest in systems with light straw provision, in comparison to giving no straw, but also to deep straw being present all the time. The authors suggested that this might be due to the addition of straw regularly increasing the interest towards the straw. Also, regularly replenished straw might stay cleaner longer, and thus increase the value for the pigs. A study based on data from 93 farms in Finland (Munsterhjelm et al., 2015a) also showed a positive effect of bedding on reducing tail biting damage: farms with thick bedding (defined as less than 50% of the solid floor visible) had a lower prevalence than farms with thin (more than 50% of the solid floor visible), or no bedding. This study included very few deep bedded systems. Very few studies have attempted to study relative effectiveness of different measures to prevent tail biting, but a recent Danish study shows some interesting results: Larsen et al. (2016a) raised non-docked or docked pigs in pens with or without added straw and found that both docking and straw use was equally efficient in reducing the prevalence of tail biting, while the lowest level of tail biting was recorded in pens with docked pigs and straw.

The value of manipulable materials for pigs is affected by a number of attributes, as summarised by EFSA (2014): they should be safe for the pigs, deformable and moveable by pig manipulation, multifunctional and have feed-related properties, such as smell, taste and nutritional value. To be efficient they should also be managed so that they are novel or renewed, accessible to all pigs and hygienic and unsoiled. Generally, manipulable objects are found to be less efficient than bedding-type material in reducing the tail biting risk (EFSA, 2014), something that the farmers in the study by Valros et al. (2016) also agreed on, ranking straw as the most efficient manipulable material for preventing tail biting, followed by newspaper and hay. However, as bedding is practically difficult to use in a commercial setting, solid objects are often used, either alone, or in combination with small amounts of bedding-type material. Some examples of solid objects reducing the risk for tail biting have been reported: for example, Telkänranta et al. (2014a) showed that the use of ample, fresh wood attached horizontally to chains in fattening pig pens increased object manipulation and reduced both tail and ear damage as compared to pens with single chains, branched chains or plastic objects. Also jute sacks were functional in reducing tail biting damage in rearing gilts, at different ages (Ursinus et al., 2014a).

Even though it has been suggested that the current environment is more important for the risk of developing tail biting than the rearing environment (EFSA, 2007), a few studies have indicated an effect of manipulable materials in the farrowing unit on later tail biting or tail biting damage risk. In the epidemiological study by Moinard et al. (2003) an increased risk of tail biting damage was seen in farms not adding straw in the creep area, as compared to farms adding straw at least daily. Munsterhjelm et al. (2009) showed that bedding provided during the lactation phase reduced negative social behaviour, including tail biting, in the fattening phase, but also that a reduction of the level of manipulable materials from one production phase to another increased the risk for tail biting damage. Also Statham et al. (2011) suggested that a decline in the amount of straw from one phase to another might increase the tail biting risk. Telkänranta et al. (2014b) showed that giving piglets newspaper and ropes as additional manipulable materials during the lactation phase decreased the frequency of piglet-directed manipulation during the lactation period. Further, the added materials decreased the severity of tail biting damage at Week 9, even though no differences in the amount of manipulative behaviour directed towards pen-mates was no longer observed at that post-weaning stage.

5.4.3 Space allowance and group size

Space allowance has been suggested as a crucial risk factor for tail biting (Schrøder-Petersen and Simonsen, 2001), but studies have yielded inconsistent results, with most studies not showing an effect (for a review, see D'Eath et al., 2014). However, Moinard et al. (2003) reported an effect of stocking density on the risk for tail biting, with over 110 kg/m^2 during the growing phase increasing the risk for tail biting significantly. However, in this study, there was a positive correlation between the number of pigs per feeder space and animal density, thus these factors might have been confounded. Munsterhjelm et al. (2015a) reported a more or less linear effect of space allowance, ranging from 0.7 to 1.5 m^2 on reducing the prevalence of tail damage, and Scollo et al. (2016) found a high stocking density to increase the risk of tail biting damage in heavy pig production. Finnish farmers in the study by Valros et al. (2016) ranked restricting animal density as the 11th most important preventive measure for tail biting, while the Dutch farmers in the study by Bracke et al. (2013) rated space allowance as the second most important risk factor. Regarding group size, previous results also do not indicate a big effect on tail biting (D'Eath et al., 2014), while a recent study on long-tailed pigs indicated that the risk for tail biting increased when pigs were housed in groups of more than 10 pigs per pen (Palander, 2016).

5.4.4 Housing conditions: climate and flooring

Ventilation, air quality and draught are often reported as risk factors for tail biting (e.g., Schrøder-Petersen and Simonsen, 2001), but are difficult to study in practice. Some studies have, however, been able to show an effect of temperature, both high and low, being a risk for tail biting (for reviews, see Schrøder-Petersen and Simonsen, 2001; D'Eath et al., 2014). Additionally an effect of outdoor climate has been suggested (Schroder-Petersen and Simonsen, 2001), while studies on seasonal effects have been inconsistent, may be because both cold and heat stress can increase the tail biting risk. Also draught and rapid changes in temperature have been suggested as causes of seasonal differences in the tail biting prevalence, as the climate regulation systems in pig houses might be less efficient at certain times of the year (D'Eath et al., 2014). Artificial ventilation was shown to be associated to a lower risk of tail biting in one study (Hunter et al., 2001) and a well-functioning ventilation system is often referred to as very important by farmers, also seen in the study by Bracke et al. (2013), where the responding farmers ranked stable climate as the most important risk factor for tail biting. The farmers in the study by Valros et al. (2016), agreed: managing air movements (draught) was ranked 3rd out of 20 suggested measures for preventing tail biting. Also managing air quality and appropriate temperature in the pen were included in the top 10 ranked measures. Poor air quality and a non-detectable air movements, as perceived by the researcher, was an important risk factor for tail biting damage in the study on heavy pigs by Scollo et al. (2016).

The type of flooring has been connected to tail biting damage, with an increased risk in systems with fully or partly slatted floors, as compared to solid floors (Schrøder-Petersen and Simonsen, 2001; Moinard et al., 2003; Palander, 2016). The reason for this might be a correlation with a low level of bedding used on slatted floors, as also concluded by EFSA (2007). Another suggested reason for the increased risk found in slatted floor systems is that they might be connected to a higher level of noxious gases (Schrøder-Petersen and Simonsen, 2001).

5.4.5 Stockperson and farm characteristics

There are very few studies on the effect of the caretaker on the risk of tail biting, even though the human factor can be expected to play a great role for how the system is managed and how efficient intervention strategies are. The role of the caretaker was raised by the respondents to the producer questionnaire by Valros et al. (2016), suggesting that changing the caretaker might be a risk factor, and that the amount of time spent in the piggery can affect tail biting, both positively and negatively. With increasing farm size, the number of pigs to be taken care of per person usually also increases, making it more challenging to spot tail biting early, and to intervene appropriately (D'Eath et al., 2016). Moinard et al. (2003) reported an increase in the tail biting damage risk as the number of pens per stockperson increased, supporting the previous statement, but the effect of farm size on tail biting damage prevalence is, however, not clear: Munsterhjelm et al. (2015a) and Palander (2016) showed an effect of farm size on tail biting damage prevalence, as did the evaluation of the previously mentioned multinational Welfare Quality dataset (EFSA, 2014), with higher prevalences found on bigger farms. In contradiction, the reported tail biting damage occurrence was not correlated to farm size in the study by Valros et al. (2016). However, producers on larger farms did perceive tail biting damage as a bigger problem than on smaller farms (Valros et al., 2016), and in accordance, very large farms were less motivated to stop docking than smaller ones in the study by Bracke et al. (2013).

Farm type has been connected to the prevalence of tail biting, with a higher risk on integrated farms than fattening farms. This might be due to different management systems on these types of farms, including continuous filling of sections being more common on integrated farms, resulting in an increased infection pressure and level of mixing of groups, as well as compromises in the environment and feeding when trying to run a system suitable for a variable size of pigs (Valros et al., 2004, Munsterhjelm et al., 2015a). On the other hand, Palander (2016) reported the opposite, with a higher risk for tail biting in finishers on separate fattening farms than on integrated farms, with both piglet production and fattening units within the same location. They explained this to possibly be caused by the stress experienced by the pigs when transported to the fattening farms, together with bigger changes in the environment and management.

5.5 Early identification of tail biting

Early identification of a tail biting is important for efficient intervention. There are a few studies on the behaviour of pigs before tail biting damage is seen. Most of these have been reviewed and discussed by Larsen et al. (2016b), who identified four main behaviours that have potential for predicting outbreaks: increases in the activity level and restlessness, and changes in explorative behaviour towards manipulable materials and other pigs, tail posture and eating behaviour. These can be observed either at pen level to predict an outbreak, or in some cases at animal level, to help identify tail biting performers or receivers (see Table 5.2). Statham et al. (2009), Zonderland et al. (2011b) and Ursinus et al. (2014b) showed that an increased general activity or restlessness could predict a tail biting outbreak. In addition, increased chewing of objects, as well as manipulation of tails and ears have been seen before visible tail biting damage (Zonderland et al., 2011b; Ursinus et al., 2014b). Zonderland et al. (2011a) have further shown that tail biting behaviour occurs up to 6 days before the first tail biting damage can be detected. As seen in Munsterhjelm et al. (2013b), there might be considerable tail damage due to biting even in tails that appear visually intact, indicating that tail biting damage as

Table 5.2 **Behavioural changes predicting an outbreak of tail biting (originally by Camilla Munsterhjelm)**

Time before the detection of tail biting outbreak	Individual level	Group level
Months to weeks		Restlessness, exploration, manipulation of an enrichment device (preliminary evidence)
		Infrequent visits to an automatic feeder
A few (2–3) weeks	Decreasing feed intake in the receiver of biting (automatic feeder)	Infrequent visits to an automatic feeder
		Shortening bouts at the feeder, but feed intake maintained
A few (0–6) days	Decreasing feed intake in the receiver of biting (automatic feeder)	Increased overall activity and restlessness
	Performer of biting shows a special interest in the receiver's tail	Tail biting activity
	Increased manipulation of an enrichment device in performers	Straight, tucked, swinging tails
		Decreased feed intake

such does not always allow for precise estimation of the timing of the start of an outbreak. Further, in pens with tail biting already occurring or in pens where damage will be recorded in a few days, more pigs can be seen to keep their tails tucked between their legs (Zonderland et al., 2009; Statham et al., 2009). The low tail posture might be due to tails already being damaged and painful, even though a damage has not yet been recorded (Munsterhjelm et al., 2013b), and the pigs are keeping the tail tucked into protect it. A low tail posture has also been connected to a negative emotional status in pigs (Reimert et al., 2013). The pig on the right in Fig. 5.2 has its tail tucked down, probably due to biting.

Wallenbeck and Keeling (2013) and Munsterhjelm et al. (2016b) showed that the number of pen level daily feed visits at an automatic feeder decreased already as early as 9–10 weeks before a tail biting outbreak was noticed in the pen. These studies might actually report a common underlying risk factor for feeding changes and a future tail biting incidence, such as a change in the health situation within the pen, indicated by a corresponding growth dip 9 weeks before tail biting was observed in the study by Munsterhjelm et al. (2016b). Munsterhjelm et al. (2015b) showed that individual animals that were to become tail bitten decreased their feed intake already 2–3 weeks before the tail damage was diagnosed by farm staff. A rapid pen level decrease in feeding visits, duration of feeding visits and feed intake 2 weeks before a tail biting outbreak was diagnosed suggests that tail biting has actually already started much earlier. Further, Viitasaari et al. 2015 showed that tail biting receivers changed their feeding behaviour when the tail biting had just started.

Larsen et al. (2016b) concluded that there are some promising alternatives for developing automatic detection of tail biting outbreaks, including automatic recording of activity levels using pen- or animal-level sensors. Measuring the level of manipulation of objects can be automated by attaching for example automatic movement sensors to the objects (Zonderland et al., 2001; Bracke and Spoolder, 2007; Bracke, 2009). Using automatic feeding, changes in feeding behaviour could easily be recorded, but these are rather uncommon on commercial farms. Also, as suggested by Larsen et al. (2016b), there is a need for further studies on the quantities and temporal changes in these behaviour in relation to tail biting to be able to further develop algorithms and tools for automatic detection of outbreaks.

5.6 Handling tail biting outbreaks

There are very few scientific studies on efficient intervention measures for tail biting. Identifying and removing the biter has been suggested as the most efficient measure by producers (Valros et al., 2016). This is supported by Zonderland et al. (2011a) who suggested that removing the biter pig might be more efficient to stop an outbreak than removing the pig with tail biting damage. However, removing the tail biter might be challenging, as they are not always easy to identify, and as many pigs in a pen might perform tail biting (Zonderland et al., 2011a). Also, the fact that tail biting performance is not as consistent over time as receiving tail bites (Ursinus et al., 2014b), and several sources have suggested an increased interest in an already wounded tail, removing the bitten pig could also be effective.

A few studies have been undertaken on how farmers deal with outbreaks. Hunter et al. (2001) reported that UK producers most commonly removed the bitten pig, followed by addition of objects and removal of the biter. Measures taken by Dutch farmers included removing the biter or the bitten pig from the pen, and adding extra enrichment materials. They also reported to improve the climate, clip or grind the teeth of biter pigs, adding a repellant to the tails or dimming the lights (Bracke et al., 2013). Finnish farmers rated identifying and removing the biter as the most important measure, followed by adding bedding-type material, removing the bitten pig, while adding objects for manipulation, reducing animal density and using anti-biting substances on the tail rating lower on level of importance (Valros et al., 2016). Adding minerals, salts or other additional feedstuffs, mainly on the floor of the pen, was a common suggestion by the farmers themselves.

5.7 Consequences of tail biting

5.7.1 Stress and pain

Tail biting causes wounding of the tail, as well as amputation of part of, or the entire tail, which surely is painful for the pig. The pain might in many cases be repeated, as victims have been shown to be bitten multiple times (Brunberg et al., 2011). In addition to the acute pain of biting, pigs with bitten tails show an increased level of acute phase proteins, indicating infection (Heinonen et al., 2010). Viitasaari et al. (2015), however, failed to show a clear effect of nonsteroidal-anti-inflammatory drug (NSAID) treatment on feeding behaviour of pigs with tail biting damage. Bitten pigs have also been reported to have signs of increased chronic stress level, shown among others by a changed cortisol pattern and adrenal size (Valros et al., 2013; Munsterhjelm et al., 2013a).

5.7.2 Health, growth and slaughter condemnations

Most studies on the link between tail biting and health and production aspects fail to show a cause and effect relationship, but often the assumption is that damage due to tail biting leads to an increase in the risk for other health problems, such as locomotory problems (Niemi et al., 2011; Marques et al., 2012) and respiratory lesions (Kritas and Morrison, 2007; Marques et al., 2012; Munsterhjelm et al., 2013b). The reason for the increased risk might be both due to a direct spread via venous, lymphatic and cerebrospinal routes, but tail biting damage might also increase the risk for opportunistic infections (Sihvo et al., 2011).

Lesions at slaughter have been shown to increase as a result of tail biting damage, with a higher risk the more severe the tail lesion is. Abscesses, lung lesions and arthritis are typical consequences of tail biting (Valros et al., 2004; Kritas and Morrison, 2007; Marques et al., 2012). Also, carcass condemnations increase significantly due to tail biting (Valros et al., 2004; Kritas and Morrsison, 2007; Marques et al., 2012; Harley et al., 2014).

Tail biting damage has also been shown to influence growth (Zonderland et al., 2010; Sinisalo et al., 2012; Marques et al., 2012) and pigs that received more oral manipulation during the finishing period, such as ear and tail biting, grew less than other pigs in the study by Camerlink et al. (2012). Consequently a significantly reduced carcass weight in tail bitten pigs as compared to non-bitten pigs has been reported (Valros et al., 2013; Harley et al., 2014). One reason for the reduced growth might be reduced feed intake. During and after a tail biting outbreak has started, pigs with bitten tails decreased their feed consumption substantially (Wallenbeck and Keeling, 2013; Munsterhjelm et al., 2015b), with a more severe anorexia in animals that will later be culled, indicating a more serious condition (Munsterhjelm et al., 2015b). After the tail damage had been diagnosed and treated, tail biting pens, however, showed signs of compensatory growth (Munsterhjelm et al., 2016b).

Even though anecdotal evidence indicates that the most severe cases of bitten pigs are culled, or die, on-farm, there is no reliable study to quantify the influence of tail biting on on-farm mortality.

5.7.3 Economic consequences

Tail biting damage causes a substantial number of direct and indirect causes for economic losses within the production chain. These were listed by Niemi et al. (2012), and include reduced growth, increased loss due to carcass condemnations, medical costs, increased workload, an assumed increase in pig mortality and increased risk for other health problems. The costs of a tail biting damage prevalence of 12% on a farm was estimated to be between €5000 and €10,000 per year on a farm with 1000 pig places (Niemi et al., 2011). In the economic analysis of tail biting costs D'Eath et al. (2016) suggested that for each victim, a net cost of €18.96 should be subtracted from the net margin.

5.8 Consequences of tail docking

5.8.1 Pain caused by docking

5.8.1.1 Acute pain

There are several studies indicating that tail docking causes acute pain and stress, measured as behavioural and physiological responses in pigs (Herskin and Di Giminiani, Chapter 11: Pain in pigs: Characterisation, mechanisms and indicators). Physiological responses are more varied, and appear to depend on the method of docking, while behavioural studies indicate more consistent proof of docking being painful for the piglets (for reviews, see Sutherland and Tucker, 2011; Nannoni et al., 2014). Behavioural changes have been reported for at least 5 h after the docking procedure (Herskin et al., 2016). Docking increases the amount of jerking, escape attempts and vocalisations (Marchant-Forde et al., 2009). Signs of acute pain after the procedure include tail jamming, wagging, posterior scooting, sitting (Sutherland and Tucker, 2011; Nannoni et al., 2014). Sandercock et al. (2016) reported signs of mild inflammation in tails up to 1 week post-docking.

A few studies on using analgesia for reducing the acute tail docking pain have indicated some, but not full, alleviation. The vocal reaction, but not the cortisol response, to tail docking was be reduced by local anaesthetic or general anaesthesia induced by carbon dioxide (Sutherland et al., 2011). Courboulay et al. (2015) tested a NSAID alone, or the combination of the NSAID and a local anaesthetic, and showed that pain was alleviated more, but not completely, by the combined treatment. Similarly, Herskin et al. (2016) showed that local anaesthesia, but not a NSAID, reduced the pain reaction during the procedure itself, but that neither eliminated pain behaviour during the proceeding 5-h period after docking.

5.8.1.2 Chronic pain

Tail docking causes increased formation of neuromas in the tip of the tail, which might indicate altered nociceptive thresholds (Herskin et al., 2015). Neuromas have been connected to chronic pain, but so far there are no studies confirming the fact that docked tails are chronically painful. Sandercock et al. (2016) reported that changes in nociceptive processing, that might be related to pain, appear to have been resolved by Week 4 after docking. Also, no signs of increased inflammatory reaction in docked vs non-docked pigs was shown at 3 or 7 weeks of age (Sutherland et al., 2009).

5.8.2 Other consequences of docking

Marchant-Forde et al. (2009) showed that the growth rate of piglets were affected up to 14 days post-docking, when piglets were docked with hot cautery, but not when using cold clippers, but other studies have not been able to show similar results (for a review, see Nannoni et al., 2014), not allowing for any proper conclusions on the effect of docking on growth.

Tail docking has been suggested to increase the risk for infections, especially if performed under non-hygienic conditions (Valros and Heinonen, 2015). Such an effect was supported by the results from the study by Valros et al. (2004), where a significant increase of abscesses and arthritis was seen not only in freshly tail bitten pig carcasses, but also in ones with healed tail damage. A large part of the healed tail damage in this study was estimated to actually be due to docking of tails.

It has been suggested that the tail of pigs is important for the communication between pigs, and that docking will thus impair social behaviour. As discussed earlier, the tail posture is an important sign of an ongoing or beginning tail biting outbreak, and in addition, tail wagging has been linked to positive emotional arousal in pigs, while keeping the tail low might be a sign of negative emotional status (Reimert et al., 2013). However, the role of the tail in communication still warrants further study.

Tail docking has been criticised not only because it is a painful procedure (Sutherland and Tucker, 2011), but also as the risk factors for tail biting are commonly related to reduced general welfare of pigs. By docking tails, pigs can thus continue to be kept in housing and management conditions which are less optimal for their welfare than if their tails would be kept intact (Valros and Heinonen, 2015). Also, it has been suggested that the tail can be used as a measure of welfare on-farm (Spoolder et al., 2011), something that is also supported by farmers used to raise pigs with long tails (Valros et al., 2016). A recent study has shown that docking the tail is equally effective in reducing tail biting as adding straw (Larsen et al., 2016a). The fact that there are equally effective, non-invasive alternatives makes the procedure even more questionable.

5.9 Conclusions and future perspectives

Tail biting is a serious welfare and economical problem in modern pig production, and efforts are needed to prevent it further. Tail docking is used widely as a way of reducing the tail biting risk, while some countries have been able to adjust to systems where docking is not allowed. Tail biting damage can occur from the lactation period until the end of fattening, as well as in rearing gilts, and in most types of farms, including organic farms (Valros, 2010; Bracke et al., 2013) and outdoor systems (Walker and Bilkei, 2006). Tail biting damage also occurs both in docked and non-docked pigs, so it is important to remember that no single measure will totally abolish the risk for tail biting, but several measures can be taken to keep tail biting damage at an acceptable level. Such an acceptable level is still to be determined, but as an example, in Finland, where tail docking is not allowed, the majority of farmers report that a level of 1%−2% of (severe) tail biting, which is close to the level reported by Finnish abattoirs (2.3%, Valros et al., 2015), is still manageable. Valros et al. (2015) suggested that it is important to establish a level of acceptable, or manageable, tail biting, instead of waiting for a zero-incidence, before considering a more strict enforcement of the tail docking ban in the entire EU.

5.9.1 Ethical considerations

D'Eath et al. (2016) modelled scenarios where pigs were either docked or non-docked, and the environment was set as standard, or as improved in some way. They concluded that the economically most efficient way to produce pigs is to dock and not improve the housing environment, and that farmers thus are unlikely to stop docking due to economic reasons. However, animal production is not only about what is most economical, but also other aspects, such as ethics and consumer acceptance need to be considered.

Tail docking is painful, and studies indicate that the pain cannot easily be fully alleviated. Being tail bitten is probably even more painful, and the pain continues for longer, as victims are repeatedly bitten. Valros and Heinonen (2015), however, underlined the fact that when pigs are docked, 100% of the pigs experience docking pain, while some will still suffer from tail biting damage. In a non-docking scenario, more pigs will probably be bitten, but no pigs will suffer docking pain, as illustrated in Fig. 5.3 (from Valros and Heinonen, 2015).

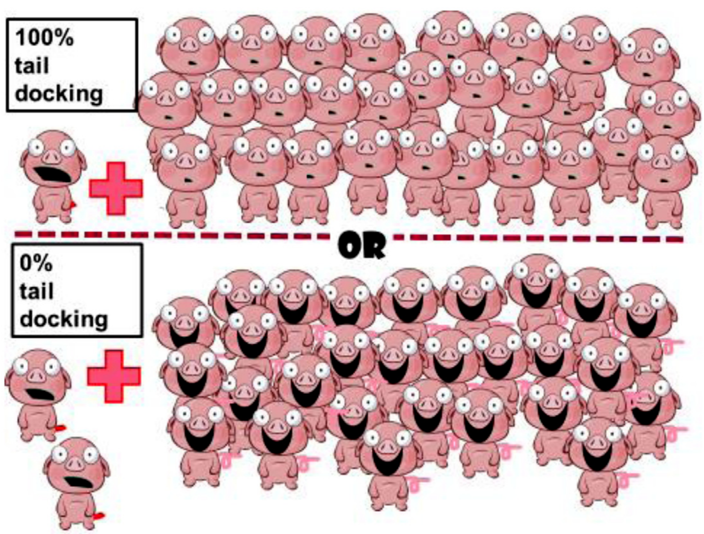

Figure 5.3 In a non-docking scenario, more pigs will probably be bitten, but no pigs will suffer docking pain.
Source: Reproduced with permission from Valros and Heinonen (2015).

D'Eath et al. (2016) suggested, based on modelling, that for tail docking to reduce the total pain experienced by the pigs compared to not docking, when docking is assumed to reduce the risk for tail biting by 50%, damage caused by tail biting should be at least 31.3 times more painful than tail docking. However, Valros and Heinonen (2015) suggested a more holistic ethical model. In this model, benefits of non-docking include also the consideration that in a system that raises pigs with long tails, the management needs to be improved to reduce the stress experienced by all the pigs. Thus, all pigs in a non-docking system potentially benefit from improved management and housing decisions.

Larsen et al. (2016a) raised the question of whether we can accept docking, which we know is painful, when we have equally efficient methods to reduce the risk of tail biting, such as adding straw. In addition, it has been shown that there is potential to raise pigs with long tails in intensive farming systems without a clear increase in the tail damage prevalence (EFSA, 2014). Furthermore, experience from countries like Finland, where tail docking is totally forbidden, shows that in practice tail biting does not increase exponentially, while it does take some years for farmers to get used to rearing long-tailed pigs (personal communication by Ylikännö, M., and Heikkilä, T., chairman and vice chairman of the Finnish Pig Entrepreneurs in 2016). In Finland, however, only approximately 20% of producers were docking tails when the tail docking ban came into force in 2003. Farmers were then given a transition period of 57 days to stop docking, which did not allow for large changes in the production system before the ban came into force.

5.9.2 Future research topics

In order to further decrease the risk of tail biting damage, and thus the perceived need for tail docking, certain areas need further research attention. We still lack solid information on the motivational background of tail biting, which makes it challenging to identify and rank risk factors, as well as to design breeding programs. There appears to be potential to reduce the problem of tail biting by improved breeding strategies, and studies are needed on how to efficiently identify relevant phenotypes.

Some risk factors have been studied rather thoroughly, while others need more attention. These include, among others, the influence of health and feeding, and individual predisposing traits of pigs. The effect of risk factors on the actual occurrence of tail biting behaviour are often difficult to study in controlled experiments, partly due to the unpredictable nature of tail biting behaviour. In addition, such experiments are ethically questionable. Thus, there is a need to develop models where the tail biting risk can be estimated without relying on actual outbreaks of tail biting. Further, to better understand the consequences of tail biting damage and tail docking, more studies are needed on adverse effects of these, and on the role of the tail for the pig. To facilitate intervention when tail biting outbreaks occur, especially on large farms, automated detection and warning systems should be developed.

As studies have shown some disagreement between researchers and farmers on the best way forward regarding reducing the perceived need for tail docking by reducing tail biting risks, and as a non-docking policy might not be economically attractive to farmers, studies should also focus on better understanding the farmers' perspective. Further, more exchange of knowledge between farmers, researchers, policy makers, both nationally and internationally would help facilitate the process of reducing the perceived need for tail docking (Valros et al., 2015).

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Abbreviations

EFSA European Food Safety Authority
NSAID nonsteroidal anti-inflammatory drug
TIM tail-in-mouth behaviour

References

Benard, M., Schuitmaker, T.J., de Cock Buning, T., 2014. Scientists and Dutch pig farmers in dialogue about tail biting: unravelling the mechanism of multi-stakeholder learning. J. Agric. Environ. Ethics. 27, 431–452.

Bracke, M.B.M., 2008. Richpig: a semantic model to assess enrichment materials for pigs. Anim. Welfare. 17, 289–7286.

Bracke, M., 2009. Rope test may indicate efficacy of tail-biting treatments in growing pigs. Anim. Welfare. 18, 263–7286.

Bracke, M., Ettema, K., 2014. Pigs suffering from injurious behaviours like flank biting and tail biting are more interested to manipulate a novel rope than uninjured control animals. In: Spink, A.J., Loijens, L.W.S., Woloszynowska-Fraser, M., Noldus, L.P.J.J. (Eds.), Proceedings of Measuring Behavior 2014, Wageningen, The Netherlands, August 27–29, 2014. Available from: http://www.measuringbehavior.org/files/2014/Proceedings/Bracke,%20M.B.M.;%20Ettema,%20K.%20-%20MB2014.pdf.

Bracke, M., Spoolder, H.A.M., 2007. Novel object test can detect marginal differences in environmental enrichment in pigs. Appl. Anim. Behav. Sci. 109, 39–48.

Bracke, M., Vermeer, H., Bokma, M., van der Peet, C., Bolhuis, L., Leeijen, J., 2012. Checklist Aanpak staartbijten bij (biologische) varkens, WUR publications. Available from: http://www.wur.nl/nl/Publicatie-details.htm?publicationId = publication-way-343237303731.

Bracke, M.B.M., De Lauwere, C.C., Wind, S.M.M., Zonderland, J.J., 2013. Attitudes of Dutch pig farmers towards tail biting and tail docking. J. Agric. Environ. Ethics. 4, 847–868.
Bracke, M., 2017. Chains as proper enrichment for intensively-farmed pigs? In: Špinka, M. (Ed.), Advances in Pig Welfare. Woodhead Publishing, Duxford, UK.
Breuer, K., Sutcliffe, M.E.M., Mercer, J.T., Rance, K.A., Beattie, V.E., Sneddon, I.A., Edwards, S.A., 2003. The effect of breed on the development of adverse social behaviours in pigs. Appl. Anim. Behav. Sci. 84, 59–74.
Breuer, K., Sutcliffe, M.E.M., Mercer, J.T., Rance, K.A., O'Connel, N.E., Sneddon, I.A., Edwards, S.A., 2005. Heritability of clinical tail-biting and it's relation to performance traits. Livest. Prod. Sci. 93, 87–94.
Brunberg, E., Wallenbeck, A., Keeling, L.J., 2011. Tail biting in fattening pigs: associations between frequency of tail biting and other abnormal behaviours. Appl. Anim. Behav. Sci. 133, 18–25.
Brunberg, E., Jensen, P., Isaksson, A., Keeling, L.J., 2013a. Behavioural and brain gene expression profiling in pigs during tail biting outbreaks—evidence of a tail biting resistant phenotype. PLoS One. 8, e66513.
Brunberg, E., Jensen, P., Isaksson, A., Keeling, L.J., 2013b. Brain gene expression differences are associated with abnormal tail biting behaviour in pigs. Genes Brain Behav. 12, 275–281.
Camerlink, I., Bijma, P., Kemp, B., Bolhuis, J.E., 2012. Relationship between growth rate and oral manipulation, social nosing, and aggression in finisher pigs. Appl. Anim. Behav. Sci. 142, 11–17.
Camerlink, I., Ursinus, W.W., Bijma, P., Kemp, B., Bolhuis, J.E., 2015. Indirect genetic effects for growth rate in domestic pigs alter aggressive and manipulative biting behaviour. Behav. Genetics. 45, 117–126.
Courboulay, V., Gillardeau, M., Meunier-Salaun, M.C., Prunier, A., 2015. La prise en charge de la doleur lors de la caudectomie et de lan castration des procelets [Pain relief at piglet tail docking and castration]. Journ. Rech. Porcine Fr. 47, 235–240.
D'Eath, R.B., Arnott, G., Turner, S.P., Jensen, T., Lahrmann, H.P., Busch, M.E., Niemi, J.K., Lawrence, A.B., Sandøe, P., 2014. Injurious tail biting in pigs: how can it be controlled in existing systems without tail docking? Animal. 8, 1479–1497.
D'Eath, R.B., Niemi, J.K., Vosough Ahmadi, B., Rutherford, K.M.D., Ison, S.H., Turner, S.P., Anker, H.T., Jensen, T., Busch, M.E., Jensen, K.K., Lawrence, A.B., Sandøe, P., 2016. Why are most EU pigs tail docked? Economic and ethical analysis of four pig housing and management scenarios in the light of EU legislation and animal welfare outcomes. Animal. 10, 687–699.
Edwards, S., 2011. What do we know about tail biting today? Pig J. 66, 81–86.
EFSA, European Food Safety Authority, 2007. Scientific Opinion of the Panel on Animal Health and Welfare on a request from commission on the risks associated with tail biting in pigs and possible means to reduce the need for tail docking considering the different housing and husbandry systems. EFSA J. 611, 1–13.
EFSA, European Food Safety Authority, 2014. Scientific opinion concerning a multifactorial approach on the use of animal and non-animal-based measures to assess the welfare of pigs. EFSA J. 12 (3702).
Harley, S., Boyle, L.A., O'Connell, N.E., More, S.J., Teixeira, D.L., Hanlon, A., 2014. Docking the value of pigmeat? Prevalence and financial implications of welfare lesions in Irish slaughter pigs. Anim. Welfare. 23, 275–285.

Heinonen, M., Toomas Orro, T., Kokkonen, T., Munsterhjelm, C., Peltoniemi, O., Valros, A., 2010. Tail biting induces a strong acute phase response and tail-end inflammation in finishing pigs. Vet. J. 184, 303–307.
Herskin, M.S., Thodberg, K., Jensen, H.E., 2015. Effects of tail docking and docking length on neuroanatomical changes in healed tail tips of pigs. Animal. 9, 677–681.
Herskin, M.S., Di Giminiani, P., Thodberg, K., 2016. Effects of administration of a local anaesthetic and/or an NSAID and of docking length on the behaviour of piglets during 5 h after tail docking. Res. Vet. Sci. 108, 60–67.
Herskin, M.S., Di Giminiani, P., 2017. Pain in pigs: Characterisation, mechanisms and indicators. In: Špinka, M. (Ed.), Advances in Pig Welfare. Woodhead Publishing, Duxford, UK.
Hunter, E.J., Jones, T.A., Guise, H.J., Penny, R.H.C., Hoste, S., 2001. The relationship between tail biting in pigs, docking procedure, and other management practices. Vet. J. 161, 72–79.
Keeling, L.J., Wallenbeck, A., Larsen, A., 2012. Scoring tail damage in pigs: an evaluation based on recordings at Swedish slaughterhouses. Acta Vet. Scand. 54, 32.
Kritas, S.K., Morrison, R.B., 2004. An observational study on tail biting in commercial grower-finisher barns. J. Swine Health Prod. 12, 17–22.
Kritas, S.K., Morrison, R.B., 2007. Relationships between tail biting in pigs and disease lesions and condemnations at slaughter. Vet. Rec. 160, 149–152.
Larsen, M.L.V., Andersen, H.M.L., Pedersen, L.J., 2016a. Both tail docking and straw provision reduce the risk of tail damage outbreaks, ISAE congress 2016. Available from: http://www.applied-ethology.org/hres/2016%20ISAE%20Edinburgh.pdf.
Larsen, M.L.V., Andersen, H.M.L., Pedersen, L.J., 2016b. Can tail damage outbreaks in the pig be predicted by behavioural change? Vet. J. 209, 50–56.
Marchant-Forde, J.N., Lay Jr, D.C., McMunn, K.A., Cheng, H.W., Pajor, E.A., Marchant-Forde, R.M., 2009. Postnatal piglet husbandry practices and well-being: the effects of alternative techniques delivered separately. J. Anim. Sci. 87, 1479–1492.
Marques, B.M.F.P.P., Bernardi, M.L., Coelho, C.F., Almeida, M., Morales, O.E., Mores, T.J., Borowski, S.M., Barcellos, D.E.S.N., 2012. Influence of tail biting on weight gain, lesions and condemnations at slaughter of finishing pigs. Pesq. Vet. Bras. 32, 967–974.
Martínez-Trejo, G., Ortega-Cerrilla, M.E., Rodarte-Covarrubias, L.F., Herrera-Haro, J.G., Figueroa-Velasco, J.L., Galindo-Maldonado, F., Sánchez-Martínez, O., Lara-Bueno, A., 2009. Aggressiveness and productive performance of piglets supplemented with tryptophan. J. Anim. Vet. Adv. 8, 608–611.
Moinard, C., Mendl, M., Nicol, C.J., Green, L.E., 2003. A case control study of on-farm risk factors for tail biting. Appl. Anim. Behav. Sci. 81, 333–355.
Munsterhjelm, C., Peltoniemi, O.A.T., Heinonen, M., Hälli, O., Karhapää, M., Valros, A., 2009. Experience of moderate bedding affects behaviour of growing pigs. Appl. Anim. Behav. Sci. 118, 42–53.
Munsterhjelm, C., Brunberg, E., Heinonen, M., Keeling, L., Valros, A., 2013a. Stress measures in tail biters and bitten pigs in a matched case–control. Anim. Welfare. 22, 331–338.
Munsterhjelm, C., Simola, O., Keeling, L., Valros, A., Heinonen, M., 2013b. Health parameters in tail biters and bitten pigs in a case–control study. Animal. 7, 814–821.
Munsterhjelm, C., Heinonen, M., Valros, A., 2015a. Application of the Welfare Quality® animal welfare assessment system in Finnish pig production, part II. Associations between animal-based and environmental measures of welfare. Anim. Welfare. 24, 161–172.

Munsterhjelm, C., Heinonen, M., Valros, A., 2015b. Effects of clinical lameness and tail biting lesions on voluntary feed intake in growing pigs. Livest. Sci. 181, 210−219.

Munsterhjelm, C., Heinonen, M., Valros, A., 2016a. Can tail-in-mouth -behaviour in weaned piglets be predicted by behaviour and performance?. Appl. Anim. Behav. Sci. 184, 16−24, http://dx.doi.org/10.1016/j.applanim.2016.08.013.

Munsterhjelm, C., Nordgreen, J., Heinonen, M., Janczak, A.M., Valros, A., 2016b. Feeding behaviour and performance in relation to injurious tail biting in boars − a longitudinal study. IPVS 2016. Royal Dublin Society, Dublin, p. 627. Available from: http://imgpublic.mci-group.com/ie/PCO/IPVS_ESPHM_2016_Book_of_Abstracts.pdf (accessed 23.09.16).

Munsterhjelm, C., Nordgreen, J., Aae, F., Heinonen, M., Olstad, K., Aasmundstad, T., Janczak, A.M., Valros, A., 2017. To be blamed or pitied? The effect of illness on social behavior, cytokine levels and feed intake in undocked boars. Physiol. Behav. 179, 298−307.

Nannoni, E., Valsami, T., Sardi, L., 2014. Tail docking in pigs: a review on its short- and long-term consequences and effectiveness in preventing tail biting. Ital. J. Anim. Sci. 13, 98−106.

Niemi, J.K., Sinisalo, A., Valros, A., Heinonen, M., 2011. The timing and treatment of tail biting in fattening pigs. In: Keynote Paper Prepared for Presentation at the 24th NJF Congress, Uppsala, Sweden, p. 6.

Niemi, J.K., Sinisalo, A., Valros, A., Heinonen, M., 2012. Market and policy-oriented incentives to provide animal welfare: the case of tail biting. In: Proceedings of the 126th EAAE Seminar New Challenges for EU Agricultural Sector and Rural Areas, Which Role for Public Policy? Capri, 2012. Available from: http://ageconsearch.umn.edu/handle/125957 (accessed 23.09.16).

Palander, P., 2016. The tail biting pig—nutritional and physiological approaches to understanding the behavior. PhD Thesis, Univeristy of Helsinki, Finland.

Palander, P., Heinonen, M., Simpura, I., Edwards, S., Valros, A., 2013. Jejunal morphology and blood metabolites in tail biting, victim and control pigs. Animal. 7, 1523−1531.

Palander, P.A., Valros, A., Heinonen, M., Edwards, S.A., 2012. Supplementary feed offered to a tail biting pen changes feeding behaviour, feed intake, growth and tail health of fattening pigs. In: Proceedings of the 46th Congress of the International Society for Applied Ethology, Vienna, Austria. Wageningen Academic Publishers. p. 156. Available from: http://www.applied-ethology.org/hres/ISAE%202012%20Vienna%20Proceedings%20PDF1.pdf (accessed 23.09.16).

Paoli, M.A., Lahrmann, H.P., Jensen, T., D’Eath, R.B., 2016. Behavioural differences between weaner pigs with intact and docked tails. Anim. Welfare. 25, 287−296.

Reimert, I., Bolhuis, J.E., Kemp, B., Rodenburg, T.B., 2013. Indicators of positive and negative emotions and emotional contagion in pigs. Physiol. Behav. 109, 42−50.

Sandercock, D.A., Smith, S.H., Di Giminiani, P., Edwards, S.A., 2016. Histopathological characterization of tail injury and traumatic neuroma development after tail docking in piglets. J. Comp. Pathol. 155, 40−49. Available from: http://dx.doi.org/10.1016/j.jcpa.2016.05.003.

Schrøder, P.D., Simonsen, H.B., 2001. Tail biting in pigs. Vet. J. 162, 196−210.

Schrøder-Petersen, D.L., Heiskanen, T., Ersbøll, A.K., 2004. Tail-in-mouth behaviour in slaughter pigs, in relation to internal factors such as: age, size, gender, and motivational background. Acta Vet. Scand. Sect. A: Anim. Sci. 54, 159−166.

Scollo, A., Contiero, B., Gottardo, E., 2016. Frequency of tail lesions and risk factors for tail biting in heavy pig production from weaning to 170 kg live weight. Vet. J. 207, 92−98.

Sihvo, H.K., Simola, O., Munsterhjelm, C., Syrjä, P., 2011. Systemic spread of infection in tail-bitten pigs. In ESVP/ECVP Proceedings 2011, p. 73.

Sinisalo, A., Niemi, J., Heinonen, M., Valros, A., 2012. Tail biting and production performance in fattening pigs. Livest. Sci. 143, 142–150.

Spoolder, H., Bracke, M., Mueller-Graf, C., Edwards, S., 2011. Preparatory work for the future development of animal based measures for assessing the welfare of pig – Report 2: Preparatory work for the future development of animal based measures for assessing the welfare of weaned, growing and fattening pigs including aspects related to space allowance, floor types, tail biting and need for tail docking. Technical report, EFSA, Parma, Italy. Available from: http://www.efsa.europa.eu/en/supporting/pub/181e.htm (accessed 23.09.16).

Statham, P., Green, L., Bichard, M., Mendl, M., 2009. Predicting tail-biting from behaviour of pigs prior to outbreaks. Appl. Anim. Behav. Sci. 121, 157–164.

Statham, P., Green, L., Mendl, M., 2011. A longitudinal study of the effects of providing straw at different stages of life on tail-biting and other behaviour in commercially housed pigs. Appl. Anim. Behav. Sci. 134, 100–108.

Sutherland, M., Bryer, P.J., Krebs, N., McGlone, J.J., 2009. The effect of method of tail docking on tail-biting behaviour and welfare of pigs. Anim. Welfare. 18, 561–570.

Sutherland, M.A., 2015. Welfare implications of invasive piglet husbandry procedures, methods of alleviation and alternatives: a review. N. Z. Vet. J. 63, 52–57.

Sutherland, M.A., Tucker, C.B., 2011. The long and short of it: a review of tail docking in farm animals. Appl. Anim. Behav. Sci. 135, 179–191.

Sutherland, M.A., Davis, B.L., McGlone, J.J., 2011. The effect of local or general anesthesia on the physiology and behavior of tail docked pigs. Animal. 5, 1237–1246.

Taylor, N.R., Main, D.C.J., Mendl, M., Edwards, S.A., 2010. Tail-biting: a new perspective. Vet. J. 186, 137–147.

Taylor, N.R., Parker, R.M.A., Mendl, M., Edwards, S.A., Main, D.C.J., 2012. Prevalence of risk factors for tail biting on commercial farms and intervention strategies. Vet. J. 194, 77–83.

Telkänranta, H., Bracke, M., Valros, A., 2014a. Fresh wood reduces tail and ear biting and increases exploratory behaviour in finishing pigs. Appl. Anim. Behav. Sci. 161, 50–59.

Telkänranta, H., Swan, K., Hirvonen, H., Valros, A., 2014b. Environmental enrichment before weaning reduces tail biting in growing pigs. Appl. Anim. Behav. Sci. 157, 14–22.

Telkänranta, H., Edwards, S.A., 2017. Lifetime consequences of the early physical and social environment of piglets. In: Špinka, M. (Ed.), Advances in Pig Welfare. Woodhead Publishing, Duxford, UK.

Temple, D., Courboulay, V., Velarde, A., Dalmau, A., Manteca, X., 2012. The welfare of growing pigs in five different production systems in France and Spain: assessment of health. Anim. Welfare. 21, 257–271.

Tetsuo, W., Munehiko, N., Kenichi, N., Toshiya, H., Masato, A., 2015. Examination of managing methods to relieve tail biting in piglets – effects of chain/rope, sodium chloride and diet form. Jpn. J. Swine Sci. 52, 123–134.

Thodberg, K., Jensen, K.H., Jørgensen, E., 2010. The risk of tail-biting in relation to level of tail-docking. In: Proc. 44th Congress of the International Society for Applied Ethology (ISAE): Coping in Large Groups, 2010, pp. 91–1.

Turner, S.P., Camerlink, I., Baxter, E., D'Eath, R.B., Desire, S., Roehe, R., 2017. Breeding for pig welfare: opportunities and challenges. In: Špinka, M. (Ed.), Advances in Pig Welfare. Woodhead Publishing, Duxford, UK.

Ursinus, W.W., Wijnen, H.J., Bartels, A.C., Dijvesteijn, N., Van Reenen, C.G., Bolhuis, J.E., 2014a. Damaging biting behaviors in intensevly kept rearing gilts: the effect of jute sacks and relations with production characteristics. J. Anim. Sci. 92, 5193–5202.

Ursinus, W.W., Van Reenen, C.G., Kemp, B., Bolhuis, J.E., 2014b. Tail biting behaviour and tail damage in pigs and the relationship with genera behaviour: predicting the inevitable? Appl. Anim. Behav. Sci. 156, 22–36.

Ursinus, W.W., Van Reenen, C.G., Reimert, I., Bolhuis, J.E., 2014c. Tail biting in pigs: blood serotonin and fearfulness as pieces of the puzzle? PLoS One. 9, e107040.

Valros, A., 2010. Hur mår djuren i ekologisk produktion? In: Johansson, B. (Ed.), Formas Fokuserar: Jordbruk som håller i längden. Formas fokuserar, Stockholm.

Valros, A., 2015. Housing and management strategies to reduce tail biting. In: Plenary Talk at the 66th Annual Meeting of the EAAP, Warsaw, Poland.

Valros, A., Heinonen, M., 2015. Save the pig tail. Porcine Health Manag. 1, 2. Available from: http://dx.doi.org/10.1186/2055-5660-1-2.

Valros, A., Ahlström, S., Rintala, H., Häkkinen, T., Saloniemi, H., 2004. The prevalence of tail damage in slaughter pigs in Finland and associations to carcass condemnations. Acta Agric. Scand. Sect. A: Anim. Sci. 54, 213–219.

Valros, A., Munsterhjelm, C., Puolanne, E., Ruusunen, M., Heinonen, M., Peltonemi, O., Pösö, R., 2013. Tail bitten slaughter pigs show alterations in stress physiology and carcass characteristics. Acta Vet. Scand. 55, 75.

Valros, A., Palander, P., Heinonen, M., Munsterhjelm, C., Brunberg, E., Keeling, L., Piepponen, P., 2015. Evidence for a link between tail biting and central monoamine metabolism in pigs (*Sus scrofa domestica*). Physiol. Behav. 143, 151–157.

Valros, A., Munsterhjelm, C., Hänninen, L., Kauppinen, T., Heinonen, M., 2016. Managing undocked pigs – on-farm prevention of tail biting and attitudes towards tail biting and docking. Porcine Health Manag. 2, 2. Available from: http://dx.doi.org/10.1186/s40813-016-0020-7.

Van de Weerd, H.A., Docking, C.M., Day, J.E.L., Edwards, S.A., 2005. The development of harmful social behaviour in pigs with intact tails and different enrichment backgrounds in two housing systems. Anim. Sci. 80, 289–298.

Viitasaari, E., Hänninen, L., Heinonen, M., Raekallio, M., Peltoniemi, O., Valros, A., 2015. Tail biting and pain: effect of ketoprofen-treatment on eating behaviour and weight gain in fattening pigs. Porcine Health Manag. 1, 11. Available from: http://dx.doi.org/10.1186/s40813-015-0005-y.

Walker, P.K., Bilkei, G., 2006. Tail-biting in outdoor pig production. Vet. J. 171, 367–369.

Wallenbeck, A., Keeling, L.J., 2013. Using data from electronic feeders on visit frequency and feed consumption to indicate tail biting outbreaks in commercial pig production. J. Anim. Sci. 91, 2879–2884.

Westin, R., 2003. Svansbitning hos gris relaterat till individuell tillväxt och ras, Examensarbete 2000: 46, Veterinärprogrammet, Veterinärmedicinska fakulteten, SLU, Uppsala.

Wilson, K., Zanella, R., Ventura, C., Johansen, H.L., Framstad, T., Janczak, A., Zanella, A.I., Neibergs, H.L., 2012. Identification of chromosomal locations associated with tail biting and being a victim of tail-biting behaviour in the domestic pig (*Sus scrofa domesticus*). J. Appl. Genet. 53, 449–456.

Zonderland, J., Vermeer, H., Vereijken, P., Spoolder, H., 2001. Measuring a pig's preference for suspended toys by using an automated recording technique. In: Proceedings of the International Symposium of the C.I.G.R. Animal Welfare Considerations in Livestock Housing Systems, 2nd Technical Section, pp. 147–156. Available from: https://ecommons.cornell.edu/handle/1813/10310 (accessed 23.09.16).

Zonderland, J.J., van Riel, J.W., Bracke, M.B.M., Kemp, B., den Hartog, L.A., Spoolder, H.A.M., 2009. Tail posture predicts tail damage among weaned piglets. Appl. Anim. Behav. Sci. 121, 165–170.

Zonderland, J.J., Bracke, M.B.M., den Hartog, L.A., Kemp, B., Spoolder, H.A.M., 2010. Gender effects on tail damage development in single- or mixed-sex groups of weaned piglets. Livest. Sci. 129, 151–158.

Zonderland, J.J., Kemp, B., Bracke, M.B.M., den Hartog, L.A., Spoolder, H.A.M., 2011a. Individual piglets' contribution to the development of tail biting. Animal. 5, 601–607.

Zonderland, J.J., Schepers, F., Bracke, M.B.M., den Hartog, L.A., Kemp, B., Spoolder, H.A.M., 2011b. Characteristics of biter and victim piglets apparent before a tail-biting outbreak. Animal. 5, 767–775.

Zupan, M., Janczak, A.M., Framstad, T., Zanella, A.J., 2012. The effect of biting tails and having tails bitten in pigs. Phys. Behav. 106, 638–644.

Chains as proper enrichment for intensively-farmed pigs?

6

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6.1 EC Directive

Directive 2001/93/EC states that:

> Pigs must have permanent access to a sufficient quantity of material to enable proper investigation and manipulation activities, such as straw, hay, wood, sawdust, mushroom compost, peat or a mixture of such, which does not compromise the health of the animals *(Article 4 of the Annex, EC (2001))*.

This may sound like a clear requirement, but in fact it is not. This is because the Directive's formulation contains words like 'proper' and 'such as'. To implement the Directive, therefore, it is necessary to answer the question of what are proper enrichment materials for pigs. This has proven to be a difficult question (CIWF, 2008, 2014). It is still largely unresolved despite the fact that the Directive should have been implemented in all EU member states as of January 2003. More recently, the European Commission also drafted new guidelines, both in 2014 (EC, 2014) and in 2016 (EC, 2016a), trying to clarify the matter. The new guidelines are ambitious, but not obligatory and lacking detailed specifications. Hence their effective implementation may generate considerable challenges. Science-based decision support to improve pig enrichment, therefore, is urgently needed.

This chapter aims to address the question what is proper enrichment for intensively-farmed pigs as implied by the Directive. It focuses on enrichment materials that aim to provide 'proper investigation and manipulation activities'. Such manipulable materials are primarily intended to provide occupation and reduce boredom. Boredom results from the fact that pigs, which have evolved to spend a considerable proportion of their time exploring and foraging (typically by rooting), have little else to do in barren pens in intensive farming systems except for eating (briefly) and sleeping. This frustration of the behavioural needs of exploration and foraging leads to abnormal, harmful social behaviours especially in the form of tail biting in growing/fattening pigs (SVC, 1997) as well as to stereotypies such as bar-biting of sows in stalls. In accordance with this all materials listed in the Directive (straw, hay, wood, etc.), except sawdust, have been shown to be able to provide occupation and/or reduce abnormal biting behaviour (SVC, 1997; Bracke et al., 2006). Tail biting is a multifactorial problem (see Valros, Chapter 5: Tail biting), with a partly unpredictable and variable occurrence. This makes it difficult to study

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(EFSA, 2007b) such that it is virtually impossible to use a reduction in tail biting as the main criterion of whether a (new) material is to be regarded as proper enrichment. Hence, the primary objective of proper enrichment material is to provide occupation, also called 'animal—material interactions' (AMI). The secondary objective is to prevent abnormal/psycho-pathological biting behaviours among groupmates like ear, flank and tail biting, and such that in particular the mutilation of routine tail docking, which has also been banned in the Directive, is no longer needed. Two additional requirements for what may be considered proper in accordance with the Directive are that manipulable materials must be (1) permanently available and (2) not compromise pig health.

In this chapter I address the issue of what is proper enrichment material for intensively-farmed pigs from my perspective through the various projects I have been involved with. Based on that experience I will formulate practical recommendations for the short-term implementation of the so-called branched-chain design and the long(er) term application of what I have labelled 'Intelligent Natural Design' (IND).

6.2 RICHPIG

In order to help the Dutch ministry decide what may be regarded as proper enrichment, we reviewed the scientific literature (Bracke et al., 2006), consulted experts (Bracke, 2006) and developed the RICHPIG model (Bracke et al., 2007a,b; Bracke, 2008). The model contains 130 enrichment materials and 30 weighted assessment criteria to determine overall enrichment value (Bracke, 2008).

Fig. 6.1 shows the conceptual framework underlying RICHPIG.

Progressive feedback loops in the framework indicate that the animal's welfare is good when proper enrichment satisfies the pigs' need to explore and forage. When the enrichment is deficient, the animals will redirect their attention and show pen- and pen-mate directed behaviour. Note that this may imply a mechanism resembling the principle of communicating vessels (connected containers filled with liquid; see Wikipedia, 2016c). In accordance with this principle pigs may distribute their (motivation for) exploratory behaviour (the liquid) depending on the quality of the manipulable 'materials' available to them (cf. Bracke et al., 2012). Eventually, an outbreak of tail biting may occur, potentially evoking a positive feedback loop (an escalating outbreak) leading to cannibalism when no 'proper enrichment' is provided buffering and/or eliminating the (primary) cause/stressor.

The conceptual framework emphasises that the pigs' need for enrichment is affected by their evolutionary and life history. Pigs have evolved to root in forest soil using their rooting disks, mainly involving downward, floor-directed behaviour. In other words, pigs are not built to reach up to straw racks or twist their heads to bite vertical wooden logs. Similarly life history, e.g., rearing on straw, may enhance the pig's need for exploration and put the animal at risk when access to straw is subsequently denied (Munsterhjelm et al., 2009). In addition, the experience of tail

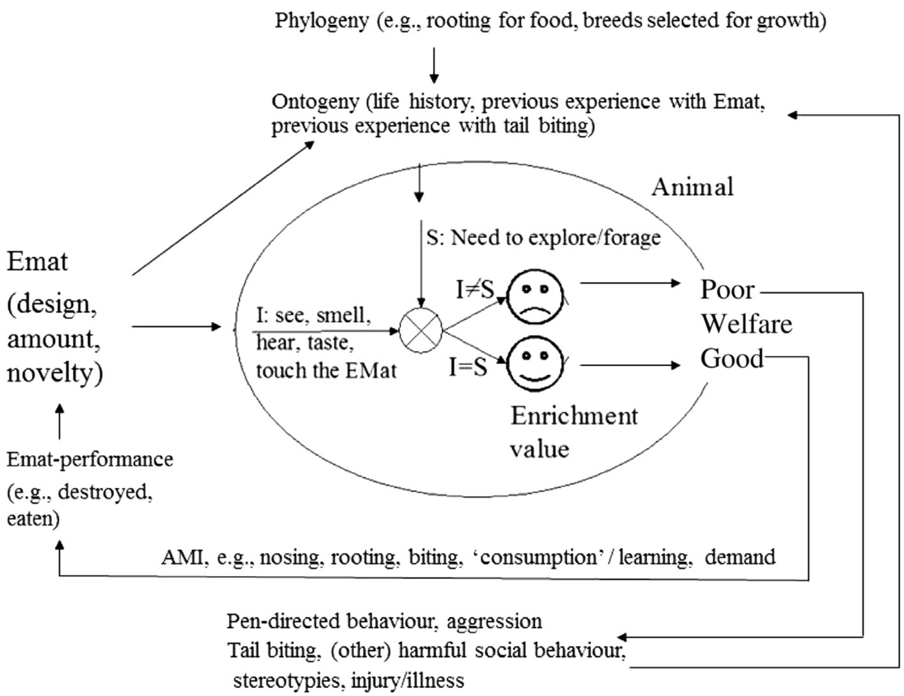

Figure 6.1 Schematic representation of the conceptual framework for assessing environmental enrichment for pigs. EMat: enrichment material; AMI: animal–material interaction; I: Istwert, the environment as perceived by the animal; S: Sollwert, setpoint or norm (modified homeostatic model after Wiepkema (1987) and (Anonymous, 2001)). *Source*: Modified from Bracke (2008), permission granted by UFAW.

biting may further enhance the need for exploration (of tails and enrichment) as indicated by the tendency of tail biting outbreaks to escalate (Fraser, 1987).

The conceptual framework also provides the ordering principle for RICHPIG's assessment criteria. In total RICHPIG has 30 assessment criteria, classified as object-design criteria (e.g., novelty and accessibility), behavioural elements (e.g., nose, root, chew), biological functions/needs (explore and forage), manipulations (i.e., object- and penmate-directed behaviours), other (non-manipulative) consequences (e.g., aggression and stress) and object-performance criteria (e.g., destructibility and hygiene) (Bracke, 2008). Assessment criteria that generated the highest weightings included (known effects on) tail and ear biting, AMI and rooting (Bracke et al., 2007b). In the final model weighting factors ranged from 12.5 for (being able to reduce) 'Tail and ear biting' to 1.2 for 'Movability' (Bracke et al., 2007b; Bracke, 2008) (see also Van de Weerd et al., 2003).

A subset of 64 materials was evaluated by 9 international pig welfare experts (Bracke et al., 2007a). Materials generating the lowest scores (on a scale from 0, low, to 10, high) included a mirror, a concrete block, a rubber mat, a minimal amount of straw, a mineral block, a heavy plastic ball, a chain (with or without hard wood attached to it), a rubber-hose cross, a free toy (sow neck tether), a hanging car tyre, a bucket, an additional operant feeder, a fixed wood block, bite rite (i.e., a plastic cone with 'tail-like' projections), and a knotted rope (all median expert scores <2.5). Materials that generated high scores included forest soil, roughage, fodder beet, maize silage, grass (silage), whole straw with chopped beet roots, with maize silage or with additional feed, a bale of straw, long straw with fir branches and straw with forest bark and branches (all median expert scores ≥ 7.0). The experts suggested a score of 5.0 as the minimum score they considered acceptable enrichment, and this included materials such as compost from a dispenser, straw pellets (loose or from a plastic dispenser) and straw in a metal basket (cited from Spoolder et al., 2011).

Based on the RICHPIG study and a follow-up study initiated by the pig sector (Ten Have-Mellema and Van Gemert, 2006) also looking at economic consequences (Zonderland, 2007) the Dutch Ministry decided that a most minimal welfare improvement would be acceptable. As of July 2007 the Ministry no longer accepted the prevalent short metal chain, but it would allow such chain if it had some indestructible synthetic/plastic material attached to it (Verburg, 2007). Only car tyres were excluded because they may contain metal parts that can be ingested (LNV, 2007). In the years after 2007 Dutch intensive pig farmers, i.e., those not involved in the Better Life welfare scheme, gradually attached indestructible materials, esp. hockey-type balls and polyethylene pipe, to the end of the chain.

6.3 Communication

Our next project focused on reducing tail docking, now involving the issue of 'proper enrichment' as one of many measures to prevent and treat tail biting, and (eventually) to keep the pigs' tails intact (see Table 6.1).

In 2008 we conducted a telephone interview among 487 conventional and 33 organic pig farmers in The Netherlands (De Lauwere et al., 2009; Bracke et al., 2013). We found that conventional farmers mainly used metal chains (52%–63% of the farms) and hanging rubber or plastic balls (22%–30%). Other reported materials were a ball or jerrycan loose in the pen: 15%–19%; chain with plastic hose around it: 15%–20%; other plastic or rubber toys: 8%–12%. Non-synthetic materials (wood, rope, straw, sawdust, woodshavings, roughage) were only used marginally (all < 10%).

We also made information about enrichment and tail biting available on the website called www.hokverrijking.nl (Dutch for 'pen enrichment'), and we developed a tool box for farmers to deal with tail biting. The website was also used in a separate project where the objective was to provide more proper enrichment in the outdoor run of organic pigs. As the outdoor runs in organic farming are often rather barren enclosures with a slatted floor, the design challenge for providing proper

Table 6.1 Overview of communication time points concerning pig enrichment (including legislation drafting and implementation, and timing of research projects)

Date	Event
1994	Dutch legislation on pig enrichment (Barren pen no longer allowed; short chain is ok; Anonymous, 1994)
August 2001	EC Directive issued on proper pig enrichment (EC, 2001)
January 2003	EC Directive ought to have been implemented (EC, 2001)
2003	NGO calls on Dutch Ministry of agriculture to enforce 1994 legislation to provide a chain (Bleijenberg, 2003)
August 2003	Start of RICHPIG project (3 years; Verburg, 2007)
May 2006	Alarm letter of pig sector to ministry about enrichment (Ten Have-Mellema and van Gemert, 2006)
2006	End of RICHPIG project
2007	Project initiated by pig sector to weigh in other values (especially economics; Zonderland, 2007)
July 2007	Dutch guidelines specified (short chain is no longer sufficient; chain with ball or pipe is ok; LNV, 2007)
2008–11	Project 'Ending tail docking'/'Responsible tail management'
2008	Farmer survey (De Lauwere et al., 2009)
2010–11	Information and tool box for farmers to deal with tail biting; prize contest (www.hokverrijking.nl)
September 2010	Dutch pig sector was informed about welfare deficit of ball/pipe and promising alternative (branched chain; Bracke, 2010a)
2011	Farmers optimistic about pig enrichment (Questionnaire Livestock Fair) in relation to Better Life
	RICHPIG calculations balls/pipe implementation in NL implied saving about 71 million Euros at a loss of 376 million enrichment-value life-points compared to soft-wood over the period 2003–11
2013–16	FareWellDock project (www.farewelldock.eu)
2015	Enrichment (chain + ball/pipe) mostly implemented in NL (NVWA, 2015a,b)
March 2016	New EC guidelines/recommendations on enrichment and tail docking (EC, 2016a,b)
2016	Pig expert questionnaire confirms value of branched-chain design (Bracke, submitted)

enrichment in organic pens was found to be remarkably comparable to the challenges encountered in conventional pens.

In addition, a small questionnaire ($n = 34$ pig farmers) was conducted on the hockey-type ball that had been implemented rather widely on pig farms in The Netherlands (Bracke, 2011d). It showed that pig farmers did not consider the investment in the balls acceptable, and they significantly lowered their appreciation of the welfare benefits of the ball when they had such a ball in their own barn (compared to when they did not). This suggests that the hockey-type balls raised higher expectations than were actually realised, both in terms of economy and pig welfare.

Furthermore, a compact questionnaire was also distributed at a livestock fair in The Netherlands in October 2011. As many as 72% of all respondents ($n = 1687$) regarded enrichment as an opportunity for livestock husbandry, and they expressed a very high (up to 95%) level of optimism regarding environmental enrichment. This was probably related to the recent introduction of the Better Life (Beter Leven) welfare scheme of the Dutch Society for the Protection of Animals. This provided conventional livestock farmers with an opportunity for some additional economic benefit. For pigs it entailed providing some extra space (1.0 instead of 0.8 m^2/pig), enrichment materials (e.g., a straw briquette), minimum tail length (>2.5 cm at docking) and the rearing of intact boars. The types of enrichment provided in the Better Life scheme, however, could be optimised. In particular the straw briquette was introduced, made up of a cylinder of pressed, short-chopped straw held in a PVC holding pipe. Like the hockey ball, the briquette enrichment probably looked, in my opinion, nicer than it really was. Apparently, farmers seemed to be providing a minimal amount of straw by restricting the pigs' access to the straw briquette (e.g., by making it protrude minimally from the PVC holding pipe (Van den Berg, 2016; Weber, 2016) and sometimes failing to de-block or refill containers timely. As indicated by the RICHPIG model and consulted experts a minimal amount of straw has very limited welfare benefits to the pigs (average expert score <2.5 where 5.0 would have been acceptable). It may even reduce welfare due to inducing frustration and competition.

Hence, when considering the issue of what is proper enrichment, it is important to be aware of preconceived ideas, potential bias and anthropomorphism. The term 'enrichment' suggests a welfare improvement, or even a welfare bonus, but that may at times be little more than a human expectation or perception. Furthermore, the term enrichment (or 'better life') can be a euphemism. When a material improves welfare, it may formally be correct to label it as enrichment, but when the pigs are otherwise still kept under most barren conditions at a very low level of overall welfare, it would be more appropriate to use the term 'de-barrenment' instead of enrichment. Some researchers also prefer to avoid the term enrichment altogether, because the term is too general and because, rather than providing something 'extra', pig enrichment deals primarily with manipulable materials which the pigs can use as a minimum fulfilment of their need to root and explore (A. Valros, pers. comm.).

Another example of human perception of pig enrichment, in which I have been involved, is the computer game for pigs, called Pig Chase (HKU, 2011; Van Peer, 2012; Anonymous, 2012). Its primary objective was to trigger ethical thinking about pig farming. In addition, what I found interesting about the idea of a computer game for pigs is that it could challenge the pig's cognitive abilities, in my view a much neglected aspect of pig enrichment. Pig Chase shows pigs interacting with a gamer via an iPad. When the pig follows a red dot controlled by the gamer, it is 'rewarded' by fireworks. This is not proper enrichment for pigs. Fireworks are nice for people. Similarly, balls are nice for people (especially because they are associated with sports), and chains are not perceived as nice. In the perception of the general public, metal chains are more likely to be associated, perhaps unconsciously, with prisons and slavery, and, for those who are a bit more knowledgeable, with the stereotyped chain chewing seen in tethered sows (Schouten and Wiegant, 1996). As these underlying emotions and associations may have contributed to the general appreciation of balls and lack of appreciation of chains as pig enrichment, it is important to be aware of the distinction between our human perceptions and what is important for the pigs themselves.

6.4 On-farm observations

In on-farm work, often with the help of students, the poor state of enrichment in conventional pig farming, as already indicated by the RICHPIG work, was confirmed. I had seen farms, some of them suffering from high levels of tail biting, where the hockey-type balls were dry and collecting dust, and where pigs were frustrated when they tried to grab the ball (see also Fig. 6.3B later in this chapter). Also bigger balls provided loose on the floor can often be seen lying in the dunging area without any persistent enrichment value to the pigs.

Our more systematic (scientific) observations in pregnant sows, weaned piglets and growing/fattening pigs kept in different housing systems repeatedly indicated that the pigs were interacting less with the chain when relatively hard, indestructible balls or plastic/synthetic tubes had been attached to the end of the chain (Ettema, 2010a,b). Perhaps chain manipulation reduces stress, as has been shown for the early phases of chain chewing in tethered sows (Schouten and Wiegant, 1996). Hence, and as farmers sometimes suggest, perhaps interacting with the end of a metal chain is comparable to chewing gum or playing with a pencil in human adolescents. When the chain is on the floor, it allows some form of rooting on the chain, and the interaction may be comparable to stone chewing which is prevalent in outdoor sows (Horrell et al., 2001). Most farmers opted for rather indestructible (and hence cost-efficient) materials (balls and pipe), e.g., by hanging them a bit higher when they had to be replaced so they are less easily destroyed. Thus the 'add-ons' were found to be mostly inferior compared to the flexible end of a freely available metal chain. Plastic materials are probably better when they are more destructible (e.g., as indicated by Courboulay, 2006, 2011). However, destructible plastic materials (tylene, alkathene, PVC, etc.) need replacement and they pose an environmental risk as they are ingested or they are degraded by the pigs and end up in the slurry pit (Spoolder et al., 2011).

We also found that pigs interacted more and for a longer period of time with a branched chain (Fig. 6.2) compared to various other enrichment devices such as a chain with hard, hockey-type plastic ball attached to it, a loose ball on the floor, a large wood block, a short chain hanging from the ceiling, and a short chain attached close to the floor (Wind, 2012). With branched chains pigs have access to the ends of a chain both at floor level and at nose height. This gives pigs the opportunity to choose, and we found that pigs interact more than twice as often with the chain end

Figure 6.2 Branched chain, i.e., a chain reaching to floor level where the chain may be 'rooted' or manipulated while lying down, and to which two short pieces of chain have been added such that ends of a chain are available at nose height to pigs of different sizes or age groups for manipulation while standing. (Note, however, that this is a c-chain, not a stainless-steel anchor chain, which is recommended.)

lying on the floor than as with the pieces of chain ending at nose height (Wind, 2012). In other words, pigs seem to prefer to 'root' on the chain that is lying on the floor, and they can manipulate such a chain while the pigs themselves are lying on the floor (which is not possible with the conventional, short chain ending at nose height).

Even organic pigs with access to straw bedding have been observed to interact extensively with branched chains and similar designs (e.g., a round chain with rings for 'rooting' (which they did not use) and branches (which they did)). This implies branched chains may have enrichment value even when straw is provided, despite the fact that straw has been shown to be used much more extensively (Scott et al., 2007) and is known to reduce tail biting (Zonderland et al., 2008). It is not expected that branched chains will substantially reduce tail biting. This remains to be shown, however, and longer chains have been shown to substantially reduce ear biting under compromised conditions of limited access to a water nipple (De Grau et al., 2005). However, branched chains do provide substantially enhanced (longer and supplemented quality) occupation (AMI) for the pigs compared to the conventional, short metal chain. This makes them suitable candidates for what may be regarded as proper enrichment material for intensively-farmed pigs. The indestructible materials I have encountered are not better, most often worse, than the short metal chain, thus worse than a branched chain. By contrast, compared to alternative, more destructible materials (like ropes, jute, soft wood, substrates), branched chains are probably, but not always, used less (Bracke, 2007, Ettema, 2010). However, branched chains are much more feasible (lower cost, less labour for maintenance, less risk of blocking of the manure system), more hygienic (reduced health/biosecurity risk), probably better for the environment, and they provide a much better guarantee of being permanently

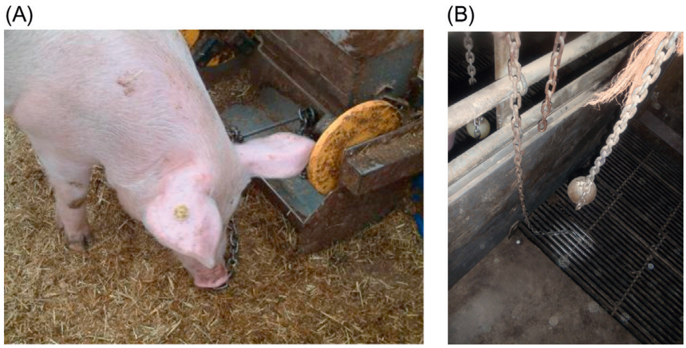

Figure 6.3 (A) Pig manipulating an anchor-type chain on the floor covered with straw. The feeder (actually a rooting bin) in the picture was permanently empty and not used for feeding or rewarding the pigs. Note that the chain is a stainless-steel anchor chain, which has more rounded links than the cheaper and apparently less preferred c-chain. (B) Balls dry and collecting dust near a short chain and a chain reaching until the floor. Note how the short chain is rusty (hanging too high) and that the metal slats are shining indicating intensive use of the chain on the floor.
Source: (A) Photo by Herman Vermeer.

available as required by the EC Directive, and (hence) they also much better allow for verification of actual compliance. Furthermore, branched chains can be specified much more accurately and uniformly than any of the destructible alternatives (and such detailed specifications are given below). This is because destructibility is difficult to measure objectively, and because many qualities codetermine the suitability of destructible materials (e.g., wood, straw and rope come in many different types, sizes and processing stages/freshness). In other words, branched chains are much more suitable candidates for being used as a standard or benchmark (reference point) against which other materials can be compared. Note, however, that such a benchmark for proper pig enrichment, does not entail it must be proper, i.e., provide a sufficient level of occupation, in and of itself. Expert opinion strongly suggests branched chains should be regarded as providing almost proper enrichment (Bracke, submitted). These chains, therefore, provide a most suitable starting point for further enrichment, also because other objects can be attached to the branched chains. Furthermore, even when branched chains are supplemented by substrates on the floor, such as roughage or straw, the pigs have been found to remain interested in the branched chain, providing a background enrichment that will remain permanently available, even when the substrates or other destructible materials are not (Fig. 6.3).

Several important conclusions can be drawn from our modelling work and on-farm observations:

1. A short metal chain without attachment consistently elicited more manipulation and investigation activities by the pigs than the same chain at the end of which a rather indestructible hockey-type ball or pipe had been attached. As pigs clearly prefer to manipulate the end of a chain over a ball and pipe, such materials are not proper enrichment materials for

pigs (see also (EFSA, 2007a,b; Spoolder et al., 2011). Such 'enrichment' is more properly referred to as impoverishment.

2. The short chain can be improved upon, especially using a branched-chain design reaching in part down to floor level (see also Parmentier, 2007).
3. The RICHPIG model was designed to support decision making to implement the EC Directive in The Netherlands. By the end of 2010 it became clear that welfare had more likely been reduced and that branched chains provided a possible solution (Bracke, 2010a). In 2011 I quantified pig welfare in The Netherlands using the RICHPIG model together with available data about the numbers of pigs raised in The Netherlands (CBS, 2011) and economic data about enrichment materials (Zonderland, 2007). I calculated the economic investment and welfare discrepancy between chains with/without balls and pipe on the one hand and a soft-wood beam on the other between 2003 and 2011 (when I did the calculations; Bracke, 2011d). The soft wood was taken as an example of a more proper (although not fully proper) enrichment material than the plastic objects (Bracke, 2008; Bracke et al., 2007a; EC, 2016a). My calculation over the period 2003–10 resulted in a total of 70 million years of pig life experiencing a welfare discrepancy of 376 million enrichment-value life-points. This is equivalent to roughly 140 million pigs experiencing a reduction of 2.7 enrichment/welfare RICHPIG points for the balls/pipes compared to the soft-wood beam provided in their 6-month life span each. In addition, I found that the Dutch pig sector had invested about 4.7 million Euros in the balls and pipes, whereas the soft-wood beam was estimated at 76 million Euros (Bracke, 2011d). This illustrates how welfare models based on semantic modelling like the RICHPIG model and/or expert opinion scores cannot only be used to support future decision making, but also to calculate welfare effects (here, a lifetime 2.7 RICHPIG points improvement for a cost of 0.5 Euro per pig) related to decisions that have been made in the past, as well as welfare benefits that may be obtained by pursuing suggested welfare solutions.

These findings also strongly emphasise the need for empirical observations to underpin claims about enrichment. New materials should preferably be tested properly before they are released onto the market. This led us to examine feasible and flexible tools, so-called AMI sensors, to assess enrichment value more objectively.

6.5 Animal–material interaction sensors

6.5.1 Introduction

The term AMI sensor was coined by Johan Zonderland. AMI stands for animal–material interactions. AMI sensors may record object use in various ways. Zonderland et al. (2001) used an electrical circuit to detect AMI in different hanging materials that were changed weekly. They found renewed interest immediately after introduction, indicating that novelty is important for pig enrichment. Earlier, Grandin had used mechanical counters to record levels of toy use (Grandin, 1989). I also used mechanical counters, e.g., to show that repellents, such as Dippel's oil and Stockholm tar, can reduce the pigs' interest in a novel rope (Bracke, 2009). Similarly, soiling with faeces reduced rope manipulation, while making the rope more destructible enhanced rope manipulation (Bracke, 2007). As of 2013 the FareWellDock project enabled further work on AMI sensors. To validate their use we explored whether we could determine enrichment value either directly or indirectly. Direct measurements record movement of the enrichment materials to which the AMI sensors have been attached. Indirect measurements are intended to detect an effect of one enrichment (e.g., substrate) by recording AMI of another material (e.g., a rope). Based on the principle of communicating vessels, indirect AMI measurements assume that if the enrichment material of interest (e.g., substrate) has a higher enrichment value, it should reduce the interest in the recorded material (e.g., rope). In the next four subsections, examples are given of the use of AMI sensors in experiments that investigated the effects variables such as feed restriction, tail and flank biting, streptococcus infection, and maize silage provision in the use enrichment materials.

6.5.2 Food restriction prior to anaesthesia

We used Icetag loggers to record AMI directly by attaching the loggers to a jute sack (reaching to the floor) and a bare metal chain ending at nose height. Both materials were simultaneously present in a pen with two pigs. The pigs were also subjected to a brief (12−24 h) period of food deprivation prior to propofol anaesthesia. Three such incidences were logged. In accordance with expectations (Feddes and Fraser, 1994; Ursinus et al., 2014b), the pigs interacted much more with the destructible jute sack than with the indestructible chain (Fig. 6.4). In addition, on

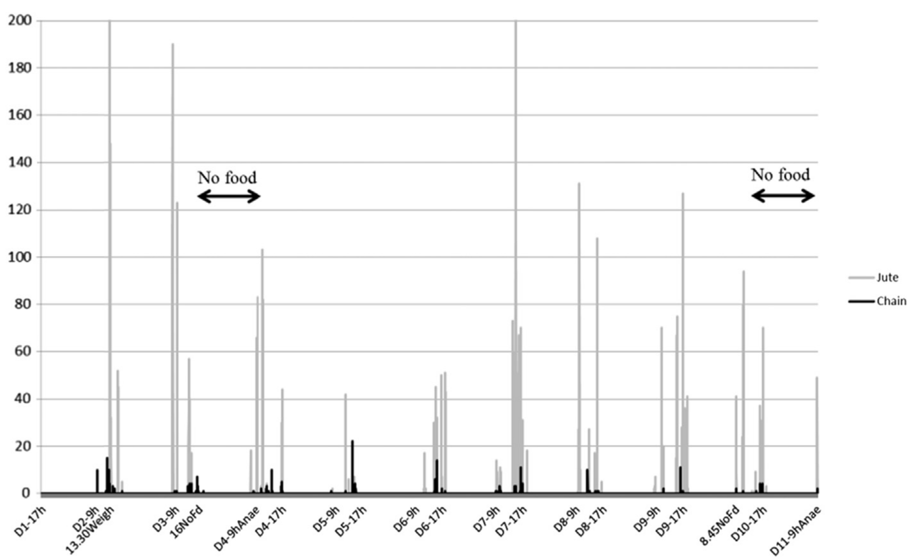

Figure 6.4 Icetag Motion Index, expressed as a value ranging from 0 to 280 and from 0 to 22 for jute sack and chain respectively, on a minute-by-minute basis over 11 days in a pen with two pigs. D: day number − time (h: hour); NoFd: no food (also indicated by arrows), e.g., 16NoFd = Fd taken away at 16 h, to be available only in the afternoon of the next day (after anaesthesia); Anae: animals under anaesthesia that day (D4 and D11); D11: anaesthesia followed by euthanasia.

the day after anaesthesia, AMI values seemed depressed. In contrast to expectation, the three periods of feed deprivation prior to anaesthesia did not show clear signs of enhanced AMI. These exploratory data may well be among the first minute-by-minute recording of enrichment AMI in pigs.

6.5.3 Flank and tail biting

On one farm we did a matched control study on all pens with flank and tail biting (Bracke and Ettema, 2014). Mechanical counters were used to test the pigs' propensity to interact with a novel rope in biter and control pens. On the farm 20% of the pens had pigs with biting wounds; 5.4% concerned tail biting and 14.3% showed flank biting. In accordance with earlier findings (Bracke, 2009), the pigs lost interest in the ropes over time. Most importantly, however, we showed that biter pens interacted significantly more with the ropes compared to controls. This may indicate an enhanced need for enrichment when biting wounds are present, thus perhaps complicating the principle of communicating vessels. In other words, what is proper enrichment under normal conditions (in control pens) may not be adequate enrichment once abnormal biting behaviour has resulted in tail, ear, leg or flank biting wounds.

6.5.4 Streptococcus infection

While abnormal biting seems to be associated with an increased need for enrichment, sickness, by contrast, may reduce it. To explore the effect of sickness on AMI we (the author in collaboration with de Greeff et al.) attached IceCubes (IceRobotics, UK) to a metal chain ($n = 6$ pens with 5 pigs per pen) to record AMI before and after an experimental infection with *Streptococcus* (either *S. suis* or *S. pneumoniae*, high/low dose, intranasally/intravenously (de Greeff et al., 2016).

AMI appeared to be reduced shortly after the infection (Fig. 6.5). In other words, a streptococcus infection may reduce the pigs' propensity to interact with a chain, perhaps reflecting the experience of feeling sick (Bracke., 2016b). This indicates that AMI sensors could perhaps be(come) of value in an early warning system for disease, and thus help in early diagnostics and reduction of the use of antibiotics.

6.5.5 Maize silage

Two related experiments by Aarnink et al. investigated the effects of maize silage in the so-called Starplus barn and the thermally controlled so-called APF barn (air pathogen free barn using overpressure) at the pig research station (Swine Innovation Centre, Sterksel). The main objective of the AMI recordings was to detect indirectly whether maize silage had enrichment value by logging AMI of ropes (Bracke et al., 2015, 2014). In addition, we looked at other variables like time of day, room temperature and gender, and directly compared AMI of ropes and hockey-type balls.

In the Starplus barn (Verdoes et al., 2014) pigs are provided with additional space, roughage and outdoor access to enhance pig welfare. We found that finishing

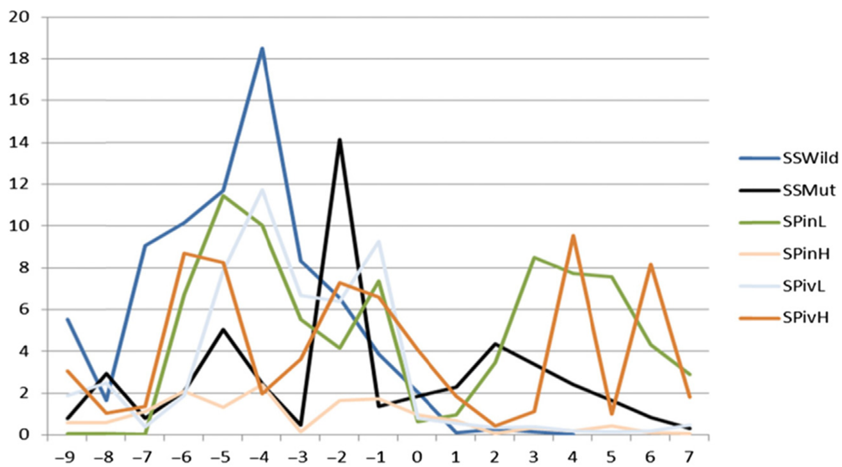

Figure 6.5 Average Motion Index values per day for the six treatments (one pen per treatment). SS: *S. suis*; Wild: wild strain; Mut: mutant strain; SP: *S. pneumonia*; iv: intravenous; in: intranasal; L: low dose; H: high dose. Day 0 is the day of infection.

pigs in the Starplus barn provided simultaneously with chopped straw and maize silage on the floor were interacting with this roughage more than pigs provided with chopped straw only. This effect lasted for about 30 min. Providing maize silage, however, had little or no effect on directly-observed behaviours (general and exploratory behaviours), nor did it have an overall effect on toy (especially rope) manipulation as measured by the AMI sensors. Furthermore, in both Starplus and APF barns, and in accordance with expectation, the AMI sensors confirmed that pigs were more interested in the sisal rope than in a hard plastic, hockey-size ball hanging on a metal chain. In the APF barn rope manipulation also appeared to be affected by maize silage enrichment in that on some days AMI was reduced when maize silage was provided. Furthermore, other variables like gender (time of), day and room temperature seemed to play a role, e.g., more reduction of rope manipulation due to maize silage at normal compared to low temperatures (Bracke et al., 2015). Overall, while these moderate amounts of maize silage (0.17−0.25 kg/pig/day) seemed to have some beneficial effects on pig welfare, we only partially managed to detect this using indirect AMI sensors on ropes, and background variables seemed to complicate the interpretation of AMI recordings. The number of pens per treatment was rather low, however, and perhaps the AMI sensors are not as sensitive as we would like, or the enrichment of maize silage is not substantial enough to be detected using indirect AMI recordings (however see Bracke and Spoolder, 2007).

6.5.6 Straw

A semi-automated novel rope test also failed to show an effect of background enrichment (straw/no straw) or gender (boars/barrows) on AMI recorded indirectly as novel rope manipulation in the Comfort Class barn (de Greef et al., 2011; Vermeer et al., 2014). Again, the number of pens was rather low ($n = 6$ per treatment) (Ettema, 2010a). In these pens ($n = 216$ growing pigs in 12 pens; 1.67 m^2/pig), three types of enrichment materials (short chain, hockey-type ball on a short chain, wooden plank on the floor) were rotated weekly. Behavioural observations showed that the wood on the floor was used much more than the hanging chain. More interestingly, the chains without balls were used more than the same chains with balls (Ettema, 2010a). While there was no effect of background enrichment (straw vs no straw) on toy use, we did find an effect of the use of automated rooting bins (cf Fig. 6.4, not containing any food reward, so functioning as a kind of AMI sensor): pigs in straw pens interacted less with the rooting bins. This suggests that AMI sensors, i.e., rooting bins, can indirectly record enrichment value (of straw), perhaps by virtue of the principle of communicating vessels between the rooting bins and straw. In accordance with this principle, rooting bins were also used more by the end of the week in which a toy (wood, chain, ball) was present compared to shortly after object rotation, when the toys were novel and attracted more interest. So perhaps the rooting bins did not only function as an AMI sensor, but also as permanently present enrichment material attracting a variable interest depending on background conditions (straw/no straw; novel/familiar toy). In this way the rooting bins themselves may even have acted as a kind of buffer, reducing the likelihood of picking up the background enrichment using the novel rope as an indirect AMI test. Using a subjective scale of biting intensity/severity, we also found that pigs without straw would bite the observer more severely than pigs kept on straw (and in another study we found that biter pigs in tail biting pens were biting the observer who was present in the pen the hardest). Furthermore, biting wounds (but not fighting wounds, i.e., deep scratches) were only observed in the pens without straw, and more tail wounds were found in pens without straw. These findings, again, seem to confirm the hypothesis of communicating vessels, indicating that enrichment value of an object (the level of AMI it attracts) may be affected by the enrichment quality of other types of enrichment provided in the pen. In other words, the more barren a pen becomes, the more important the enrichment value of an enrichment material like a metal chain (or another pig).

6.5.7 Short and (a bit) longer chains in poor and (really) rich rearing conditions

Finally, in an experiment by Van Dixhoorn et al. (2016) we did seem to be able to detect a difference between rich and poor pens (four pens per treatment; see example pens in Fig. 6.6A and B) using *indirect* AMI measurement of two chains hanging in each pen (Bracke, 2016a). Young pigs in poor pens were more interested in the chains than pigs in (very) rich pens. The poor pens were conventional farrowing and weaner pens. In the rich pens the pigs were provided with extra space, compound enrichment (straw, peat, woodshavings, jute and branches) and social rearing (two farrowing pens were joined after 1 week). This indicates that AMI sensors (IceCubes, IceRobotics, UK) may be able to detect a (substantial) contrast in

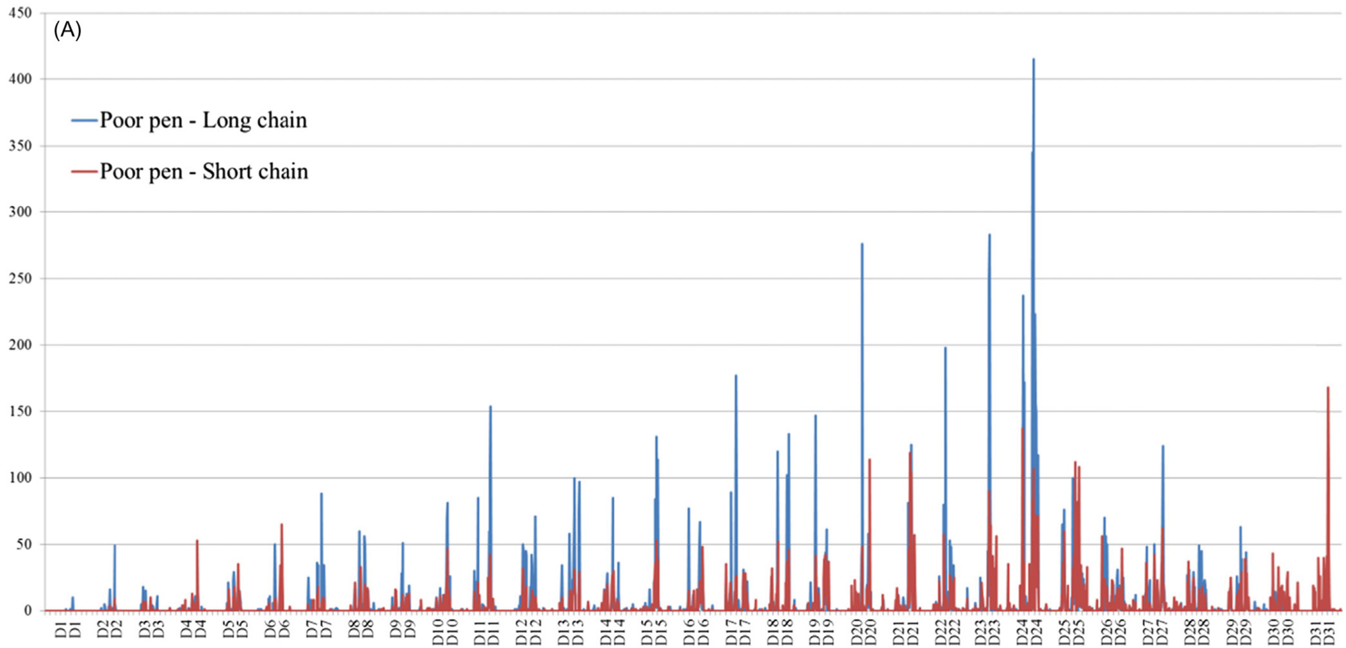

Figure 6.6 (A) Motion Index values over 31 days in the farrowing pen for a short (red) and somewhat longer (blue) metal chain in a poor pen (conventional farrowing pen). (B) Motion Index values over 31 days in the farrowing pen for a short (purple) and somewhat longer (green) metal chain in a rich pen.

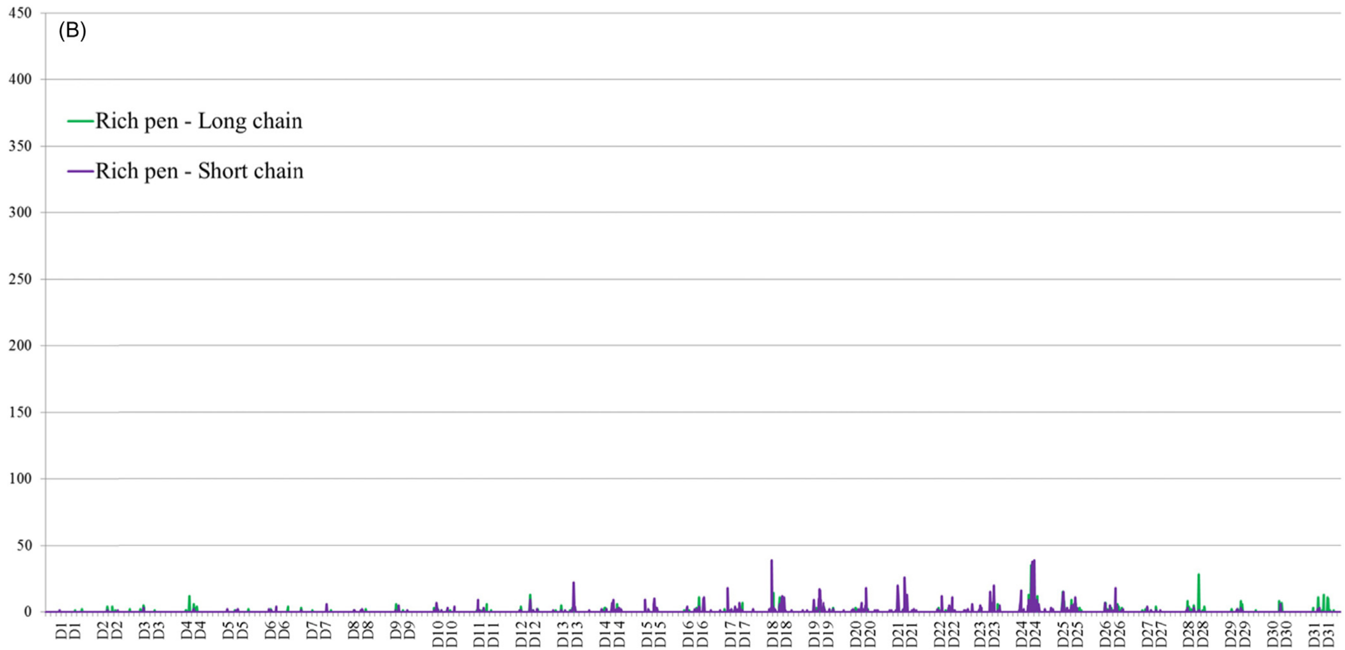

Figure 6.6 (Continued).

background enrichment in accordance with the principle of communicating vessels. The contrast between chain AMI of rich and poor pens, however, was less pronounced in the weaner pens than in the farrowing pens.

Another noteworthy finding was that in poor pens, short chains (ending at nose height) appeared to be manipulated less than 10−15 cm longer chains. The longer chains seemed to be better, even without reaching the floor. This was especially the case in the farrowing pens where the chains were hanging against the back wall and thus much less likely to be set in motion by the pigs' locomotor activity in relation to either enrichment level (more/less space) or chain length. This may indicate that the conventional short chain may even be improved upon by letting it reach a bit further down.

6.5.8 Conclusion about animal−material interaction sensors

Data obtained from AMI sensors (motion sensors) attached to hanging enrichment materials may provide valuable supplements to other ways of assessing enrichment value, i.e., expert opinion, RICHPIG assessment, direct (casual/expert) observation and experimental study.

AMI sensors are flexible, can be used on commercial farms, and they are much less expensive and labour intensive than doing a behavioural study. Compared to behavioural observations, AMI data are also more objective (i.e., more related to physics than to the interpretation of an observer). Most importantly, AMI sensors are able to provide a more comprehensive, minute-by-minute and day-and-night, record of AMI.

Disadvantages include that AMI sensors may have a limited sensitivity (e.g., may require a larger number of pens to obtain statistically significant results). AMI sensors can only be attached to certain, especially hanging, materials, out of reach of the pigs. The sensors need to resist a potentially hostile environment (e.g., moisture, biting, pulling, hitting, ammonia and dust). Furthermore, AMI sensors do not readily allow recording the behavioural elements as is conventional in behavioural studies, and special care must be taken to deal with potentially confounding factors such as different types of object interaction (e.g., manipulation versus touching the object accidentally e.g., during locomotion or pen cleaning). Specific algorithms may be developed to make more fine-grained behavioural distinctions. Also the enrichment materials themselves may affect AMI sensor data. For example, the sensors themselves may elicit attention from the pigs (especially when novel) and objects with different physical properties may show different responses to (the same type of) manipulation by the pigs. Hence, the application of AMI sensors is not as straightforward as it may appear, and further validation is needed before it can be implemented in practice to support the recording of enrichment value.

Our AMI sensor findings, however, seem to confirm existing knowledge (e.g., that a jute sack is used more than a chain; that a chain with ball is used less than a rope). We also found some confirmation of the ability of AMI sensors to (indirectly) detect contrast in background enrichment (especially when the contrast is evident). This seems to be in accordance with the hypothesis of communicating vessels. This hypothesis was originally brought to my attention by Johan Zonderland, who also initiated the work on AMI sensors at Wageningen Livestock Research. Further research is needed to establish in more detail the role of a number of factors (like nutritional status, health, thermal conditions, breed, etc.) on AMI. In this respect, health status may be of particular relevance as AMI sensors may be useful in early warning of disease and thus help reduce the use of antibiotics. Most importantly, however, given the history of providing inadequate enrichment materials (hockey-type balls, pipe, straw briquette), AMI sensors may become a valuable supplement to the behavioural observations which are evidently needed to verify RICHPIG-type assessments and other, especially commercial, claims about enrichment value.

6.6 What is proper enrichment for intensively-farmed pigs in the short term?

According to the EC Directive, as of 2003 proper investigation and manipulation materials should have been provided to all pigs at all times in all member states. Most European countries have not implemented this in accordance with the scientific communis opinio (Bracke et al., 2007a; Bracke, submitted). Here I will formulate a proposal meeting this requirement, that is feasible under current commercial conditions and can be implemented widely in the short term. The proposal is based on my own research (RICHPIG, AMI sensor data), personal observations supplemented with input from colleagues, experts (Bracke, submitted) and farmers. It is specified in more detail in a supplement, which will be made available online via http://farewelldock.eu/chain-as-enrichment-with-supplement and http://hokverrijking.nl/ketting-als-verrijking-met-supplement.

Our research indicated that the enrichment value of the short chain can be improved with little extra cost, essentially by making the chain longer, and by adding short pieces of chain, resulting in a branched chain with chain ends both resting on the floor and hanging slightly below nose height of the pigs in any stage of their development. When provided in sufficient quantity, such a branched-chain design is what I recommend as the most suitable starting point (base-line) as well as benchmark (negative control) for (developing) proper enrichment for intensively-farmed pigs. This is especially true when the ratio of enrichment value per invested Euro is taken into account. The branched-chain design implies the following conglomerate of specifications in terms of object-design, material, availability and placement:

1. *Object-design. A branched chain consists of a vertically-positioned long chain with its end resting on the solid floor over a distance of 20 cm. Two or three additional chain ends (branches) end at or slightly below the nose height of the smallest and middle-sized pigs reared in the pen.*

   This should allow pigs of all sizes to interact relatively readily with the chain ends. It also allows two or three pigs to play with the chain in the same location, thus supporting social facilitation and synchronisation. Pigs will interact with the chain in both a standing, sitting and lying position, and, most importantly, pigs can stand with their head down manipulating the end of the chain that is lying on the floor with their nose. This resembles (some rudimentary) rooting behaviour.

2. *Material. The chains are stainless-steel anchor chains (for at least the last 5–10 links of each chain end). Recommended dimensions are 7 mm for growing-fattening pigs, 5–6 mm for weaners, 4–5 mm for piglets and 8 mm for sows.*

   Anchor chains have links which are more round and heavier than the cheaper, more oval-shaped c-chains. The links of an anchor chain appear to be more pleasant for the pigs to be held in their mouths, but this is a subjective impression that remains to be confirmed. The size of the links should fit the size of the pigs' oral cavity. Note that the indicated sizes refer to the diameter of the metal, not the diameter of the links. For example, a 7 mm anchor chain for finishers has links measuring 36 × 23 mm. For rearing pens (containing growing-finishing pigs ranging in body size from about 25 to 120 kg) various chain sizes should be provided in the pen, such that the most preferred types are available for all sizes of pig. Stainless-steel anchor chains are more expensive than c-chains. However, they also last much longer. According to the farmer who recommended the chain link sizes, the stainless-steel anchor chains themselves will last 'forever'. Only the last 5 or so links need to be replaced every 5–10 years. This implies that the overall costs of the stainless-steel anchor chains remain very low, especially when secondhand chains are used. Note that the branched chain is itself equivalent to several chains hanging side by side, except that the shorter 'branches' require less material, and thus costs, to produce chain ends valued by the pigs.

3. *Availability and placement. One branched chain is provided for every five pigs. The chains are spaced apart as much as possible, preferably with at least one pig length between two branched chains in a pig pen. The branched chains are attached at the top end of the pen wall, over the solid floor, and not in the dunging area.*

   Chains should have some action radius and be accessible to the pigs, even when one chain accidentally gets blocked by a dominant or resting conspecific. So, chains in corners should be avoided, unless they are provided in surplus. Also, when the chains are getting out of reach (e.g., thrown out of the pen), alternative attachment, such as hanging them away from the pen wall, may be required. Chains hanging on the pen wall away from the corner are generally readily accessible without inducing frustration, i.e., the pigs voluntarily approach to interact with them.

6.6.1 Are branched chains really proper enrichment?

No, they are not. But they seem to be *almost* proper, and they are a major step forward, also according to an international group of pig welfare experts (Bracke, submitted). Furthermore, farmers should be able to make the last step towards proper enrichment by themselves (Table 6.2). It may only be a small step. For example, perhaps an indestructible object (which is already present in many pig pens, e.g., a ball, pipe or wood) can be added to one of the branched chains. This may well be sufficient to surpass the threshold of both scientific and current legal acceptability. However, it will probably not be enough to reduce the need for tail docking (which is also required by EU law). For this, destructible materials are probably needed. To my knowledge, however, no such materials can be recommended for widespread implementation in intensive pig farming in the short term, unless they are enforced. They are perceived as too costly even though they may cost as little as 6–13 Eurocents per kg of pig meat (carcass weight) (Zonderland, 2007; Zonderland et al., 2008). Furthermore, the materials may block the manure system and keeping

Table 6.2 **Tentative scoring of enrichment materials for intensively-farmed pigs in relation to observations reported in the text**

Score	Enrichment material
10	Ideal enrichment
≥ 7.0	Destructible materials provided properly, e.g., forest soil, roughage, fodder beet, maize silage, grass (silage), whole straw with chopped beet roots, with maize silage or with additional feed, a bale of straw, long straw with fir branches and straw with forest bark and branches (all median expert scores ≥ 7.0)
	Plenty of long straw on the floor, regularly renewed
	Compost from a dispenser, straw pellets (loose or from a plastic dispenser) and straw in a metal basket; ropes, jute, soft wood, substrates
	Branched chain + indestructible objects
5.5	Cut-off of what is minimally acceptable or 'proper enrichment' (above this line)
	Branched-chain design
	Short chain
	Destructible materials provided improperly (e.g., limited access/not destructible/ soiled), e.g., straw briquette; narrow hay rack; forced grass silage consumption; large, swinging soft wood; loose logs, rope-and-rubber, wooden plank
	Short chain with indestructible ball/pipe
< 2.5	A mirror, a concrete block, a rubber mat, a minimal amount of straw (!), a mineral block, a heavy plastic ball (on the floor), a chain (with or without hard wood attached to it), a rubber-hose cross, a free toy (sow neck tether), a hanging car tyre, a bucket, an additional operant feeder, a fixed wood block, bite rite (i.e., a plastic cone with 'tail-like' projections), and a knotted rope (all median expert scores < 2.5)
0	No enrichment (barren pen)

up maintenance is a real challenge. As a consequence, the use of destructible materials on commercial farms tends to be mitigated by practical considerations, often leading to compromised pig welfare benefits. Therefore, it is highly recommended that their enrichment value is verified, e.g., using the branched-chain design in a sufficient number of pens (e.g., 10 pens) as a benchmark.

In my view branched chains provide by far the most feasible solution for short-term pig enrichment. Many aspects of their design as well as prospects for further improvement still remain to be verified and falsified in further research. However, in answering the question 'what is proper pig enrichment in the short term?', it is better to avoid suggesting that more research is needed, at least in the classical sense of scientists working in research laboratories/research stations. Because further research could (again) lead to delays in implementation of the knowledge which is available at present.

Before the EC Directive was implemented in The Netherlands, a metal chain was considered proper enrichment. This was often a short chain, reaching not further than nose height. Such a chain would seem highly feasible, involving low cost and hardly any labour, totalling 0.25 Euro per pig per year (Zonderland, 2007). Nevertheless, farmers were reluctant to provide it as almost 10 years after prior legislation coming into force in 1994 (Anonymous, 1994), the government was still urged to enforce it (Bleijenberg, 2003). Currently, providing the legally required enrichment (i.e., adding an indestructible piece of pipe or ball to the metal chain) has been an issue until recently in The Netherlands (NVWA, 2015a,b) as well as in most other European countries (CIWF, 2013, 2014). In non-European countries, like the United States, Canada and New Zealand, most pig farmers do not provide any enrichment, apparently because it is not (considered to be) cost-effective (Bracke, submitted).

However, from a legal perspective, there is increasing pressure to improve pig enrichment. Recent EC guidelines (EC, 2016a,b) recommend that destructible materials should be provided. However, the new guidelines are neither legally binding, nor specified in much detail. Chains are classified as ‘materials of marginal interest’, which cannot be provided alone. Other marginal materials include ‘rubber, soft plastic pipes, hard plastic, hard wood, ball, salt lick’ (EC, 2016a). The new minimum recommendation appears to be to provide either a marginal material like a chain together with a so-called ‘suboptimal material’, or two suboptimal materials. Suboptimal materials include straw, hay, or silage in a rack/dispenser, soft wood, natural rope and hessian sack, but also natural soft rubber, sawdust, sawdust briquette, compressed straw in a cylinder (i.e., straw briquette), pellet dispenser and ‘sand and stones’. The guidelines have open standards on various materials, e.g., what classifies as soft wood, how accessible the straw provided in straw racks or straw briquettes must be, and what dimensions of wood would be acceptable (as e.g., large logs of soft wood can be indestructible and thus ineffective for the pigs). Also, rubber is classified in the guidelines as marginal, but natural rubber is suboptimal. Natural rubber is frequently used in materials like car tyres, and the guidelines do not specify how soft ‘soft natural rubber’ must be. Because the guidelines have open (i.e., unspecified) standards, implementation will be difficult and the overall effect on pig welfare will differ between farmers. When pig farmers try to (or are forced to) reduce costs, they may (try to) provide a stone and a chain, for example, or a straw briquette as described in the Directive and practiced in some welfare schemes in a suboptimal way (as described earlier in this chapter). Such ‘enrichments’ may have a very limited actual welfare benefit, especially when compared to providing the full branched-chain design (see the supplement: http://farewelldock.eu/chain-as-enrichment-with-supplement for more details).

Our on-farm observations also point in this direction. Conventional pigs provided with limited access to a hay rack or a soft-wood beam showed signs of frustration, enhanced aggression and skin lesions, as (conversely) did organic pigs that were fed substantial amounts of grass silage (Bikker and Binnendijk, 2012; Wind et al., 2012). Furthermore, weaners provided simultaneously with a bundle of chains hanging to floor level, a (rather big but soft) wooden plank, a rope and a flexible rubber toy (piece of hanging rubber mat), interacted about three times more with the chains than with the other materials. Also, fattening pigs simultaneously provided with a short chain and a rope with a flexible rubber flap interacted more often with the chain than with the rope-and-rubber. The rope-and-rubber was virtually indestructible, whereas the chain was a 'proper' stainless-steel anchor chain reaching about 20 cm closer to the floor than the rope-and-rubber (52 and 33 cm, respectively) (Ettema, 2010a). In these examples, the suggestion in the new guidelines that chains are inferior to the other materials, i.e., wood-rope and rope-rubber combinations, appears to be false. If so, allowing the combination of materials while rejecting the chains, seems to be suboptimal as regards pig welfare as well as suboptimal as regards the economic interests of farmers and consumers.

Economic considerations alone may justify the use of branched chains, as no alternative material seems to provide as much welfare improvement for every Euro invested in enrichment. Furthermore, indirect economic benefits may include improving pig health by reducing stress and the use of antibiotics, or perhaps by reducing the cost of tail biting (which occurs in intensive pig farming despite tail docking, Zonderland et al., 2011). But such indirect economic benefits, however, remain to be shown.

Non-economic considerations also need to be taken into account. This includes pig welfare in intensive pig farming systems, with proper enrichment being a notable item for pig welfare. The branched-chain design provides a unique opportunity for the pig sector. It can lead to proper pig enrichment and intact tails, two increasingly recognised requirements necessary to maintain a societal licence to produce. Within animal welfare, pig enrichment is special, because of its association with positive welfare, rather than with reducing suffering (as in the case of reducing tail docking, for example). Enrichment materials are very much visible to visitors and provide an opportunity to explain about pig welfare and how the pig sector is responding to societal concerns. In this way, enrichment may become the pig sector's flagship of the transition towards a better future, a future also where former enemies perhaps may become allies. The final section explains how this may happen.

6.7 Intelligent natural design

Intelligent natural design (IND) holds the promise of resolving persistent welfare problems by organising an evolutionary process resembling natural selection, e.g., by providing economic incentives to promote desirable outcomes. IND is a term coined to solve complex pig welfare problems, such as proper enrichment and intact tails, through human-made evolution (Bracke et al., 2011; Bracke, 2010b). The concept derives from a so-called TED talk entitled 'Trial, error and the God complex' (Harford, 2011). Harford explains how Unilever physicists failed to design a properly-functioning nozzle to make washing powder. The problem was finally solved by an evolutionary biologist, Steve Jones, who subjected the problem to a process of human-made evolution. Jones built 10 different nozzles as a first 'generation', selected the best ones, and repeated this trial and error selection process for 45 'generations'. It resulted in a nozzle that performed much better than the solutions scientists had been able to come up with. Harford suggests this approach can solve just about any problem. I propose it can solve the problem of providing proper pig enrichment as well. Yet, I also think the method needs refinement, because a fully 'blind' trial and error process applied to pig welfare could lead to poor welfare, putting it at risk of being unethical. Also, being a welfare scientist myself, I believe available knowledge should be used intelligently. Hence, IND expresses the ambition of an 'intelligent' evolution. IND combines the phrases 'intelligent design' and 'natural'. Natural is what happens in nature, i.e., evolution guided by natural selection. It has an impressive ability to find the most elegant solutions for very complex design problems through trial and error, i.e., without relying on scientific knowledge or intelligence. 'Intelligent design' normally refers to a religious form of creationism holding the view that certain features of the universe and of living things are best explained by an intelligent cause (Wikipedia, 2016a). 'Intelligent design' in IND, however, refers to the idea that we may intelligently design the conditions needed to facilitate gradual, evolution-like improvements towards more desirable and sustainable livestock-production systems. For this scientific understanding of underlying mechanisms is desirable, but not absolutely necessary. We should use it, where possible.

According to the principle of IND, we may organise individual variation and persistent selection to deal with pig enrichment. For this, the main selection criterion is pig occupation, i.e., the time spent in voluntary, enrichment-directed behaviour or AMI. AMI duration and the type of AMI may be recorded using behavioural observations and using AMI sensors. Pig tails provide a related selection criterion. Pig tails may be measured in terms of tail lesions and tail length. Using these criteria the selection process starts with comparing the most promising feasible enrichment materials. As a starting point, this should include the branched-chain design as described above. The enrichments are implemented in a limited number of pens ('individuals'). Enrichment materials, or combinations of materials, in pens are then compared, either as individuals or as a group of 'clones'/treatments, to see which is doing best in terms of providing pig occupation. The best, most 'fit', 'individuals'/enrichments are selected and used to 'generate', i.e., design and install, the next 'generation' in, say, a new batch of pigs. When repeated persistently, this process should inevitably lead to gradually improved enrichment. Ideally, the selection process should lead to considerably improved pig welfare. This requires the ample performance of positive, natural behaviours (Bracke and Hopster, 2006; Bracke and Spoolder, 2011) and a minimised level of abnormal behaviours, mutilations and health problems.

Farmers should be responsible for the implementation of the branched chains on their farms, and for the IND selection process and innovation. This turns farmers into a kind of pioneers for doing participative science. It implies that farmers themselves, alone or with the help of others (e.g., vets, students, scientists), make science-based comparisons. As a result, supplementing a comparison of individual instances of enrichment materials as in the case of the nozzles for making washing powder, IND proposes comparing groups/repetitions/'clones' of enrichment treatments as much as possible in accordance with scientific standards (e.g., random allocation of enrichment treatments; standardised observations, statistical analysis, etc.). This makes sense, i.e., is smart, because pig enrichment is subject to considerable individual variation (Feddes and Fraser, 1994), as is the case in nature (and much less so in washing powder nozzles). It is also smart because intensive pig farms typically have many repetitions of highly similar pig pens. This allows repetitions/'clones' of enrichment treatments to be compared at a group level, i.e., as average value and standard deviation, in addition to making a comparison at individual level. Not all farmers would have the time and skills required to do such science-based comparisons themselves. But, firstly, it is not necessary for IND to work, and, secondly, many farmers would have the skills to make it possible, e.g., through (scientifically-trained) extension and by allowing students and scientists do the work on their farm.

The main challenges include overcoming economic constraints, and redirecting farm management from its primary focus on maximised production efficiency to focusing on maximised efficiency of inclusive welfare. This includes both farmer welfare, of which economy is a most important component, and animal welfare. Seeking maximised overall welfare implies recognising that feasibility is a necessary condition. As such branched chains are feasible, and destructible materials generally are not (or not yet). It also implies that the impressive capacities of the pig sector to innovate for economic reasons can be redirected such that existing skills could innovate for improved animal welfare too. Innovating for personal financial gain often involves keeping knowledge private, because its leading principle is individual selection. By contrast, IND would promote altruism via group selection, thus suggesting that farmers share information, e.g., about which enrichments are promising and which are not. In this way the wheel does not have to be invented time and time again. Sharing also facilitates correction of potentially biased or misleading claims.

IND acknowledges that modern intensive pig production is itself the product of human-made selection, in particular of economic selection for maximised production efficiency. This implies that IND-based solutions for enrichment should work with, rather than oppose, the underlying economic forces. Current economic forces are pulling towards completely barren pens, as is practiced in most countries outside the EU. Legislative measures and welfare schemes try to counteract this. For IND to succeed, it is important to start pushing towards welfare improvements. This implies providing incentives for doing well, and imposing a (relative) material or immaterial cost on doing less well. Several examples may illustrate how different stakeholders can implement IND by creating economic and other incentives to promote innovation towards more proper pig enrichment.

The first example is for regulatory bodies to use existing EU legislation to stimulate pig welfare improvement. In particular, current EU legislation (EC, 2001) contains articles banning routine tail docking and teeth treatment at an older age. In particular, it also prescribes that 'plentiful straw' must be provided in cases of 'severe fighting' 'which goes beyond normal behaviour' (Article 3 of the Annex). Enforcing these requirements could promote better enrichment directly, e.g., by providing plenty of straw in case of tail biting (which was more commonly regarded as a form of abnormal fighting behaviour in the early days of drafting animal welfare legislation; and to some extent it may well be (e.g., when it originates at the feeder), even though ethologists now commonly agree that tail biting is not an agonistic behaviour as such). Enforcing existing legislation could also promote better enrichment indirectly, e.g., by requiring more serious efforts to stop tail docking.

A second example is more directed towards other chain actors and towards reward rather than punishment. Slaughterhouses could put a premium on pigs with longer and intact tails, at very little or no costs to themselves. The premium may be financed in various ways, e.g., through a general check-off payment by the farmers. This would imply a redistribution of (some) money from the worse to the better farmers. It may also be paid for by consumers, retailers and governments who feel this is important for sustainability. Also crowd-funding and prize-contests could be organised to generate incentives for farmers to implement the branched-chain design, and start directing innovation towards better animal welfare, proper enrichment and intact, curly pig tails in intensive pig farming (see also the supplement: http://farewelldock.eu/chain-as-enrichment-with-supplement).

A welfare scheme is also conceivable where consumers can pay directly for improved enrichment, much in the way they can already pay for green energy and for climate-neutral holiday flights. In this way welfare revenue can go more directly (via the farmers) to the pigs rather than to the intermediate actors in the supply chain as tends to happen in most current welfare schemes. In fact, the top end of enrichment, i.e., providing a sufficient amount of straw to stop routine tail docking and to raise pigs with intact curly tails on well-managed pig farms, may cost perhaps as little as about 5 (to perhaps 10) Euro per pig, i.e., 6–13 Eurocents per kg of pig meat (carcass weight) (Zonderland, 2007; Zonderland et al., 2008). If consumers would be willing to donate this kind of money to pig farmers, tail docking could soon come to an end. I even believe that the RICHPIG model (Bracke, 2008; Bracke et al., 2007a) and the more recent expert scores (Bracke, submitted) provide a fairly sound basis for the suggestion that branched chains and the IND approach could be turned into one of the most cost-effective charitable objectives available at present to tangibly improve (any kind of) animal welfare (cf effective altruism, Wikipedia, 2016b; Singer, 2015). More ideas on IND and the development of proper pig enrichment are described in the supplement at http://farewelldock.eu/chain-as-enrichment-with-supplement.

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Abbreviations

AMI animal–material interactions
IND intelligent natural design

References

Anonymous, 1994. *Varkensbesluit [Dutch Pig Directive]* [Online]. Available from: http://wetten.overheid.nl/BWBR0006806/2005-08-01.

Anonymous, 2001. Scientists' assessment of the impact of housing and management on animal welfare. J. Appl. Anim. Welf. Sci. 4, 3–52.

Anonymous, 2012. Angry birds? No happy pigs. Science. 335, 19.

Bikker, P., Binnendijk, G., 2012. Ingekuild gras voor biologisch gehouden vleesvarkens. [Grass silage for organic fattening pigs]. Report 603. Wageningen UR Livestock Research, Lelystad, The Netherlands. Available from: <http://edepot.wur.nl/166598>.

Bleijenberg, M., 2003. Ministerie van LNV houdt openbare stukken achter [Ministry of LNV is witholding public documents] [Online]. Available from: <http://www.wakkerdier.nl/persberichten/ministerie-van-lnv-houdt-openbare-stukken-achter>.

Bracke, M., Hopster, H., 2006. Assessing the importance of natural behavior for animal welfare. J. Agric. Environ. Ethics. 19, 77–89.

Bracke, M., Spoolder, H., 2011. Review of wallowing in pigs: implications for animal welfare. Anim. Welfare. 20, 347–363.

Bracke, M., Lauwere, C.C.D.E., Wind, S.M., Zonerland, J.J., 2013. Attitudes of Dutch pig farmers towards tail biting and tail docking. J. Agric. Environ. Ethics. 26, 847–868.

Bracke, M., Aarnink, A., Vermeer, H.M., 2014. Extra snijmais goed voor welzijn varkens. [Extra maize silage good for pig welfare]. *V-focus*, 34–35. Available from: <http://edepot.wur.nl/323897> (accessed 17.02.15).

Bracke, M.B.M., 2006. Expert opinion regarding environmental enrichment materials for pigs. Anim. Welfare. 15, 67–70.

Bracke, M.B.M., 2007. Multifactorial testing of enrichment criteria: Pigs 'demand' hygiene and destructibility more than sound. Appl. Anim. Behav. Sci. 107, 218–232.

Bracke, M.B.M., 2008. Richpig: a semantic model to assess enrichment materials for pigs. Anim. Welfare. 17, 289–304.

Bracke, M.B.M., 2009. Rope test may indicate efficacy of tail-biting treatments in growing pigs. Anim. Welfare. 18, 263–266.

Bracke, M.B.M., 2010a. Afleidingsmateriaal initiatief. [Enrichment materials initiative]. Unpublished email to main representatives of the pig sector, 4 September 2010. Wageningen Livestock Research.

Bracke, M.B.M., 2010b. Towards long(er) pig tails: new strategy to solve animal welfare problems. In: Lidfors, L., Blokhuis, H., Keeling, L. (Eds.), Proceedings of the 44th Congress of the ISAE, 4–7 August 2010, Uppsala, Sweden. Wageningen Academic Publishers, p. 135.

Bracke, M.B.M., submitted. Expert opinion on metal chains and other indestructible objects as proper enrichment for intensively-farmed pigs.

Bracke, M.B.M., 2011d. European legislation on enrichment fails to improve pig welfare (unpublished manuscript). Wageningen Livestock Research.

Bracke, M.B.M., 2016b. Accelerometer on play chain may detect pigs' responses to major stressors such as experimental *Streptococcus* infection (unpublished). Wageningen Livestock Research.

Bracke, M.B.M., Ettema, K., 2014. Pigs suffering from injurious behaviours like flank biting and tail biting are more interested to manipulate a novel rope than uninjured control animals. In: Spink, A.J., Loijens, L.W.S., Woloszynowska-Fraser, M., Noldus, L.P.J.J. (Eds.), Proceedings of Measuring Behavior, 27−29 August 2014. Wageningen, The Netherlands. Available from: <http://www.measuringbehavior.org/files/2014/Proceedings/Bracke,%20M.B.M.;%20Ettema,%20K.%20-%20MB2014.pdf/> (accessed 28.08.14).

Bracke, M.B.M., Spoolder, H.A.M., 2007. Novel object test can detect marginal differences in environmental enrichment in pigs. Appl. Anim. Behav. Sci. 109, 39−48.

Bracke, M.B.M., 2016a. Interaction of suckling and weaned piglets with long and short play chains while housed in barren and enriched pens (and exploratory infection with APP) (unpublished). Wageningen Livestock Research.

Bracke, M.B.M., Zonderland, J.J., Lenskens, P., Schouten, W.G.P., Vermeer, H., Spoolder, H.A.M., Hendriks, H.J.M., Hopster, H., 2006. Formalised review of environmental enrichment for pigs in relation to political decision making. Appl. Anim. Behav. Sci. 98, 165−182.

Bracke, M.B.M., Zonderland, J.J., Bleumer, E.J.B., 2007a. Expert judgement on enrichment materials for pigs validates preliminary RICHPIG model. Appl. Anim. Behav. Sci. 104, 1−13.

Bracke, M.B.M., Zonderland, J.J., Bleumer, E.J.B., 2007b. Expert consultation on weighting factors of criteria for assessing environmental enrichment materials for pigs. Appl. Anim. Behav. Sci. 104, 14−23.

Bracke, M.B.M., Wolthuis, M., Zonderland, J.J., Kluivers, M., 2011. Tails to tell—tail docking, tail biting and enrichment for pigs—experiences from the Netherlands. Herning, Denmark, 25−26 May 2011. Available from: <http://vsp.lf.dk/~/media/Files/Temagruppemode/Management%20slagtesvin/Bracke%20tilgang%20til%20halebidsproblematikken%20i%20holland.ashx> (accessed 10.05.16).

Bracke, M.B.M., Vermeer, H., Bokma, M., Van Der Peet, C., Bolhuis, L., Leeijen, J., 2012. Checklist aanpak staartbijten bij (biologische) varkens. [Checklist dealing with tail biting in (organic) pigs] Flyer. Lelystad: Wageningen Livestock Research. Available from: <http://edepot.wur.nl/220045> (accessed 11.05.16).

Bracke, M.B.M., Vermeer, H.M., Aarnink, A.J.A., 2015. Effects of maize silage and secondary variables like gender and room temperature on pig behaviour and welfare, and the use of data loggers recording toy manipulation (report). Wageningen Livestock Research (unpublished).

CBS, 2011. Landbouw, gewassen, dieren en grondgebruik naar regio (Agriculture, crops, animals and soil use by region). Centraal Bureau voor de Statistiek (Statistics Netherlands). Available from: <http://statline.cbs.nl/StatWeb/publication/?DM = SLNL&PA = 80780NED&D1 = 500-517,538,542,550&D2 = 0&D3 = 0,5,(l-2),(l-1),l&HDR = G1,G2&STB = T&VW = T>.

CIWF, 2008. The state of Europe's pigs: an exposé. Compassion in World Farming, Goldaming, Surrey, UK. Available from: <http://www.ciwf.org.uk/includes/documents/cm_docs/2008/s/state_of_europes_pigs_2008_uk.pdf> (accessed 25.01.10).

CIWF, 2013. Reports by the Food and Veterinary Office that show failure to enforce provisions of Council Directive 2008/120/EC on the protection of pigs that require enrichment materials to be provided and that ban routine tail docking. Compassion in World Farming, River Court, Surrey, UK. Available from: <http://www.ciwf.org.uk/includes/documents/cm_docs/2013/f/fvo_reports_on_failure_to_enforce_pigs_directive_compiled_by_compassion_in_world_farming_sept_2013.pdf> (accessed 20.01.16) [Online].

CIWF, 2014. Lack of compliance with the Pigs Directive continues: urgent need for change. Compassion in World Farming. Available from: <https://www.ciwf.org.uk/media/

5508030/lack-of-compliance-with-the-pigs-directive-continues-urgent-need-for-change.pdf> (accessed 25.08.16) [Online].

Courboulay, V., 2006. Intérêts comparés d'un objet fixé au sol ou d'un apport de paille comme matériaux d'enrichissement du milieu de vie pour le porc à l'engrais (Impact of straw provision or of a ground fixed object as environmental enrichments for growing-finishing pigs). J. Rech. Porcine. 38, 421–426.

Courboulay, V., 2011. Utilisation de différentes modalités de mise à disposition de chaînes pour des porcs en engraissement: impact sur le comportement et les lésions des animaux. [Chain-based objects used as enrichment toys: Effects on behavior and lesions in fattening pigs]. J. Rech. Porcine France. 43, 183–184. Available from: <http://www.cabi.org/cabdirect/FullTextPDF/2012/20123233837.pdf> (accessed 25.02.16).

De Grau, A.F., Dewey, C.E., Widowski, T.M., Friendship, R.M., De Lange, C.F., Milligana, B., 2005. Reducing weight variation and behaviour problems in nursery pigs on a commercial farm by improving water accessibility and providing environmental enrichment. J. Anim. Vet. Adv. 4, 51–57.

De Greef, K.H., Vermeer, H.M., Houwers, H.W.J., Bos, A.P., 2011. Proof of principle of the comfort class concept in pigs: experimenting in the midst of a stakeholder process on pig welfare. Livest. Sci. 139, 172–185.

De Greeff, A., Van Selm, S., Buys, H., Harders-Westerveen, J.F., Tunjungputri, R.N., De Mast, Q., van der Ven, A.J., Stockhofe-Zurwieden, N., De Jonge, M.I., Smith, H.E., 2016. Pneumococcal colonization and invasive disease studied in a porcine model. BMC Microbiol. 16, 1–8.

De Lauwere, C., Hoogendam, K., Zonderland, J., Bracke, M., 2009. Stoppen met couperen? Varkenshouders over staartbijten en staartcouperen. [Stopping tail docking? Pig farmers on tail biting and tail docking]. LEI report 2009–97. LEI, The Hague. Available from: <https://www.wageningenur.nl/nl/Expertises-Dienstverlening/Onderzoeksinstituten/livestock-research/show.htm?publicationId = publication-way-333838303639> (accessed 01.05.16).

EC, 2001. Commission Directive 2001/93/EC of 9 November 2001 amending Directive 91/630/EEC laying down minimum standards for the protection of pigs. Official Journal of the European Communities. Available from: <http://eur-lex.europa.eu/legal-content/EN/ALL/?uri = CELEX%3A32001L0093> (accessed 04.05.16).

EC, 2014. Guidelines on the provision of enrichment material for pigs. Brussels. Available from: <http://ec.europa.eu/dgs/health_food-safety/information_sources/docs/ahw/20140701_guideline_enrichment_en.pdf> (accessed 08.01.16).

EC, 2016a. Commission staff working document on best practices with a view to the prevention of routine tail-docking and the provision of enrichment materials to pigs accompanying the document Commission Recommendation on the application of Council Directive 2008/120/EC laying down minimum standards for the protection of pigs as regards measures to reduce the need for tail-docking. Available from: <http://ec.europa.eu/food/animals/docs/aw-pract-farm-pigs-staff-working-document_en.pdf> (accessed 15.03.16).

EC, 2016b. Commission recommedation (EU) 2016/336 of 8 March 2016 on the application of Council Directive 2008/120/EC laying down minimum standards for the protection of pigs as regards measures to reduce the need for tail-docking. 8 March 2016. Available from: <http://eur-lex.europa.eu/legal-content/EN/TXT/?uri = uriserv:OJ.L_.2016.062.01.0020.01.ENG&toc = OJ:L:2016:062:TOC> (accessed 23.03.16).

EFSA, 2007a. Animal Health and Welfare in Fattening Pigs in Relation to Housing and Husbandry. EFSA, Parma, Italy. Available from: <http://www.efsa.europa.eu/sites/default/files/scientific_output/files/main_documents/564.pdf> (accessed 10.05.16).

EFSA, 2007b. The Risks Associated with Tail Biting in Pigs and Possible Means to Reduce the Need for Tail Docking Considering the Different Housing and Husbandry Systems. EFSA, Parma, Italy. Available from: <http://www.efsa.europa.eu/en/efsajournal/doc/611.pdf> (accessed 10.05.16).

Ettema, K.C., 2010a. Prevention of Tail Biting Behaviour Through Increased Welfare. Student Thesis. Van Hall Larestein.

Ettema, K.C., 2010b. The underestimated value of the chain as a toy for pigs (unpublished information sheet). Van Hall-Larestein/Wageningen Livestock Research.

Feddes, J., Fraser, D., 1994. Non-nutritive chewing by pigs: implications for tail-biting and behavioral enrichment. Trans. ASAE. 37, 947–950.

Fraser, D., 1987. Mineral-deficient diets and the pig's attraction to blood: implications for tail-biting. Can. J. Anim. Sci. 67, 909–918.

Grandin, T., 1989. Effect of Rearing Environment and Environmental Enrichment on Behavior and Neural Development in Young Pigs. PhD Thesis, University of Illinois at Urbana-Champaign. Available from: <https://www.ideals.illinois.edu/handle/2142/21967> (accessed 14.05.16).

Harford, T., 2011. Trial, error and the God complex. *TED talk*. Available from: <http://www.ted.com/talks/tim_harford#t-657729> (accessed 28.06.16).

HKU, 2011. Playing with Pigs: Pig Chase. Available from: <https://vimeo.com/29046176> (accessed 25.08.16).

Horrell, R., A'ness, P., Edwards, S., Eddison, J., 2001. The use of nose-rings in pigs: consequences for rooting, other functional activities, and welfare. Anim. Welfare. 10, 3–22.

LNV, 2007. Goede afleiding voor uw varkens. [Good distraction for your pigs]. Brochure. Available from: <https://www.rijksoverheid.nl/documenten/brochures/2007/05/16/goede-afleiding-voor-uw-varkens> (accessed 01.05.16).

Munsterhjelm, C., Peltoniemi, O.A., Heinonen, M., Hälli, O., Karhapää, M., Valros, A., 2009. Experience of moderate bedding affects behaviour of growing pigs. Appl. Anim. Behav. Sci. 118, 42–53.

NVWA, 2015a. Varkens - Naleving welzijnsregels bij varkenshouders van 60% naar 74% [Pigs – Compliance animal welfare regulations among pig farmers from 60% to 74%]. Available from: <https://www.nvwa.nl/onderwerpen/dieren-dierlijke-producten/dossier/varkens/nieuwsoverzicht/nieuwsbericht/2064241/naleving-welzijnsregels-bij-varkenshouders-van-60-naar-74> (accessed 05.05.16) [Online].

NVWA, 2015b. MANCP Meerjarig National ControlPlan Nederland. Jaarverslag 2014. [MANCIP More-year control plan Netherlands. Year report 2014]. NVWA, The Hague. Available from: <https://www.nvwa.nl/actueel/bestanden/bestand/2209042/mancp-meerjarig-nationaal-controleplan-nederland-2014> (accessed 27.06.16).

Parmentier, L., 2007. Speelgoed voor varkens. [Toys for Pigs]. MSc Thesis, KU Leuven.

Schouten, W., Wiegant, V., 1996. Individual responses to acute and chronic stress in pigs. Acta Physiol. Scand. Suppl. 640, 88–91.

Scott, K., Taylor, L., Gill, B.P., Edwards, S.A., 2007. Influence of different types of environmental enrichment on the behaviour of finishing pigs in two different housing systems: 2. Ratio of pigs to enrichment. Appl. Anim. Behav. Sci. 105, 51–58.

Singer, P., 2015. The Most Good You Can Do: How Effective Altruism Is Changing Ideas About Living Ethically. Yale University Press, London.

Spoolder, H.A.M., Bracke, M., Mueller-Graf, C., 2011. Scientific report updating the EFSA opinions on the welfare of pigs – Report 2 – Update of animal health and welfare aspects in relation to housing and husbandry of weaned, growing and fattening pigs, including space, floors, tail biting and tail docking – Consisting of 3 sub-reports corresponding to 3 EFSA's scientific opinions to be updated – 31 May 2011. EFSA, Parma, Italy. Available from: <http://www.efsa.europa.eu/sites/default/files/scientific_output/files/main_documents/181e.pdf> (accessed 18.03.16).

SVC, 1997. The welfare of intensively kept pigs. Report to the Directorate General XXIV of the European Commission. Adopted 30. September 1997. Doc. XXIV/ScVc/0005/97, Scientific Veterinary Committee, Animal Welfare Section, Brussels. Available from: <https://www.google.nl/url?sa = t&rct = j&q = &esrc = s&source = web&cd = 1&ved = 0ahUKEwjaldy6is_MAhVJK8AKHUC5DogQFggiMAA&url = http%3A%2F%2Fec.europa.eu%2Ffood%2Fanimals%2Fdocs%2Faw_arch_1997_intensively_kept_pigs_en.pdf&usg = AFQjCNHhxlkkVO_On0rmCmmS2SWbYiRocg&sig2 = AlcloGs_eoFPNGQBlDU-Hg&cad = rja> (accessed 10.05.16).

Ten Have-Mellema, A., Van Gemert, W., 2006. Afleidingsmateriaal bij varkens. [Enrichment materials for pigs]. Letter to the Minister of Agriculture, C. Veerman, from LTO and NVV. Available from: <http://www.oudewebsite.ltonoord.nl/binaries/10213715_f232055994-brief-afleidingsmateriaal.doc> (accessed 05.05.16).

Ursinus, W., Wijnen, H., Bartels, A., Dijvesteijn, N., Van Reenen, C., Bolhuis, J., 2014b. Damaging biting behaviors in intensively kept rearing gilts: the effect of jute sacks and relations with production characteristics. J. Anim. Sci. 92, 5193–5202.

Valros, A., 2017. Tail biting. In: Špinka, M. (Ed.), Advances in Pig Welfare. Woodhead Publishing, Duxford, UK.

Van De Weerd, H.A., Docking, C.M., Day, J.E., Avery, P.J., Edwards, S.A., 2003. A systematic approach towards developing environmental enrichment for pigs. Appl. Anim. Behav. Sci. 84, 101–118.

Van Den Berg, B., 2016. NGO perspectives on developing and implementing a Quality Assurance scheme for improving the rearing of pigs and phasing out tail docking. In: Meeting on Actions to Prevent Tailbiting and Reduce Tail Docking of Pigs, 4–6 October 2016. Grange, Ireland. Available from: <https://circabc.europa.eu/faces/jsp/extension/wai/navigation/container.jsp> (accessed 21.10.16).

Van Dixhoorn, I.D.E., Reimert, I., Middelkoop, J., Bolhuis, J.E., Wisselink, H.J., Koerkamp, P.W.G.G., Kemp, B., Stockhofe-Zurwieden, N., 2016. Enriched housing reduces disease susceptibility to co-infection with Porcine Reproductive and Respiratory Virus (PRRSV) and *Actinobacillus pleuropneumoniae* (*A. pleuropneumoniae*) in young pigs. PLoS One. 11, e0161832. Available from: <http://journals.plos.org/plosone/article?id = 10.1371/journal.pone.0161832> (accessed 11.09.16).

Van Peer, I., 2012. TEDx talk: Playing with Pigs: Irene van Peer at TEDxBrussels. Available from: <https://www.youtube.com/watch?v = bCHMCRIHTD0> (accessed 25.08.16).

Verburg, G., 2007. Kamervragen afleidingsmateriaal voor varkens. [Parliamentary questions enrichment materials for pigs]. LNV, The Hague. Available from: <https://www.rijksoverheid.nl/documenten/kamerstukken/2007/08/14/kamervragen-afleidingsmateriaal-voor-varkens> (accessed 01.05.16).

Verdoes, N., Classens, P., Aarnink, A., 2014. STAR+: dier-en milieuvriendelijke stal. V-focus. 11, 32–33.

Vermeer, H., De Greef, K., Houwers, H., 2014. Space allowance and pen size affect welfare indicators and performance of growing pigs under Comfort Class conditions. Livest. Sci. 159, 79–86.

Weber, R., 2016. Maintaining low stress pig production-rearing pigs with intact tails. In: Meeting on actions to prevent tailbiting and reduce tail docking of pigs, 4–6 October 2016. Grange, Ireland. Available from: <https://circabc.europa.eu/faces/jsp/extension/wai/navigation/container.jsp> (accessed 21.10.16).

Wiepkema, P.R., 1987. Behavioural aspects of stress. Biology of Stress in Farm Animals: An Integrative Approach. Springer, Berlin, Germany.

Wikipedia, 2016a. Intelligent design. Available from: <https://en.wikipedia.org/wiki/Intelligent_design> (accessed 08.09.16) [Online].

Wikipedia, 2016b. Effective altruism. Available from: <https://en.wikipedia.org/wiki/Effective_altruism> (accessed 08.09.16) [Online].

Wikipedia, 2016c. Communicating vessels. Available from: <https://en.wikipedia.org/wiki/Communicating_vessels> (accessed 08.09.16) [Online].

Wind, S.M.M., 2012. The Welfare of Organic Finishing Pigs. MSc Thesis, University of Utrecht.

Wind, S.M.M., Bracke, M.B.M., Vermeer, H.M., 2012. The effect of Roughage (i.e. chopped grass silage mixed through the concentrate feed) on welfare of organic growing/finishing pigs. Wageningen Livestock Research. Unpublished report.

Zonderland, J., Vermeer, H., Vereijken, P., Spoolder, H., 2001. Measuring a pig's preference for suspended toys by using an automated recording technique. In: Proceedings of the International Symposium of the C.I.G.R. Animal Welfare Considerations in Livestock Housing Systems, 2nd Technical Section, pp. 147−156. Available from: <https://ecommons.cornell.edu/handle/1813/10310> (accessed 14.05.16).

Zonderland, J.J., 2007. Afleidingsmateriaal breed gewogen. [Enrichment materials widely weighed]. Report. Wageningen UR Livestock Research, Lelystad. Available from: <http://library.wur.nl/WebQuery/wurpubs/357049> (accessed 01.05.16).

Zonderland, J.J., Wolthuis-Fillerup, M., Van Reenen, C.G., Bracke, M.B.M., Kemp, B., Hartog, L.A.D., Spoolder, H.A.M., 2008. Prevention and treatment of tail biting in weaned piglets. Appl. Anim. Behav. Sci. 110, 269−281.

Zonderland, J.J., Bosma, A.J.J., Hoste, R., 2011. Financiële consequenties van staartbijten bij varkens. [Financial consequences of tail biting in pigs]. Report. Wageningen UR Livestock Research, Lelystad. Available from: <http://www.wageningenur.nl/en/Publication-details.htm?publicationId = publication-way-343134343230> (accessed 01.05.16).

Mitigating hunger in pregnant sows

7

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7.1 Development of dry sow feeding and housing

Pregnant, or 'dry' sows are typically not fed as much food as they would like to eat (feeding to appetite, or ad libitum), instead they are fed a limited quantity, meaning that their feed is restricted (rationed). How did this come about? Decades of breeding for rapid lean growth in grower/finisher pigs, and more recently for litter size in sows has increased appetite and growth potential (Kirkwood and Aherne, 1985) and actual adult size (Moustsen et al., 2011). Modern domestic sows, from the time that they are being reared for the breeding herd (gilts), are food-rationed otherwise they become too fat, suffering from increased lameness from joint problems and reduced longevity (Dourmad et al., 1994; Jørgensen and Sørensen, 1998). Sows are also rationed during pregnancy to limit weight and fat gain and to promote a greater feed intake during lactation, which increases energy availability for milk production, contributing to piglet growth (Hansen, 2012).

Research going back more than 50 years shows a number of production advantages to reducing energy intake in pregnancy and increasing it during lactation: First parity litter size was higher in some studies while the piglets were only slightly smaller, sows put on less weight (resulting in lower lameness and improved longevity) and total feed costs were lower so farm system efficiency was higher (Lodge, 1969; Lodge et al., 1961; Elsley et al., 1968, 1969). These findings influenced the first published set of recommendations for pig nutrition (Agricultural Research Council, 1967) which included ration feeding for pregnant sows. Later research across five parities suggested that sows that were fed more during pregnancy had a similar litter size to those fed less, and that piglets were only slightly heavier at birth (Whittemore et al., 1988) so the additional feed costs are not justified from a system efficiency point of view. The focus of all this work was on production, but when restricted pigs had their motivation to access extra feed tested in an operant task, their responses showed that food motivation was high and as such they are likely to suffer from hunger (Lawrence et al., 1988). These studies, which used boars as a model for sows, calculated that the ration allocated to sows was around 60%–70% of the quantity of food they were capable of eating ad libitum. Much of the research on optimal sow diets is now decades old, and there is a need to update recommendations for the modern hyperprolific sow (Thiel, 2015; Prunier et al., 2010), particularly due to concerns over fertility and longevity (Soede et al., 2013).

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This increased focus on restricting sow intakes during pregnancy coincided in the late 1960s and into the 1970s with increasing intensification and scale in pig farming, and wider use of artificial insemination (AI; McGlone and Salak-Johnson, 2009). There was also a move away from keeping dry sows outdoors on pasture, or in indoor systems with some outdoor access, to indoor systems with pregnant sows confined in feeding stalls (gestation crates) which are typically only 0.5−0.7 m wide and 2−2.5 m long (McGlone, 2013). To understand the degree of confinement, these dimensions should be compared to the size of an average 5th parity modern Danbred sow which is 0.44 m wide and 1.93 m long (Moustsen et al., 2011). Advantages for producers of stall housing include reduced building space, elimination of feed competition and stockworker convenience for individual management and AI (Barnett et al., 2001).

7.2 Concern over dry sow welfare

With the introduction of sow stalls, concerns arose over their negative effect on animal welfare. Confinement in space not much larger than the sow severely limits her movement and prevents most normal behaviour. As well as causing behavioural frustration, inactivity leads to poor cardiovascular fitness (Marchant et al., 1997) and weak bones and muscles (Marchant and Broom, 1996) resulting in lameness (Barnett et al., 2001). Due to feed restriction, sows in these systems remain hungry and are motivated to continue to forage for food after they have quickly eaten up their ration of concentrated food. In the absence of natural foraging opportunities, stall-kept sows show redirected oral behaviour such as biting, nosing and licking of the chain, floor and trough (Fraser, 1975), 'sham' chewing with an empty mouth (Rushen, 1985), or excessive manipulation of the drinker which may include excessive water consumption (Terlouw et al., 1991). These behaviours may become stereotypic in nature, particularly in older sows, meaning that they are performed in a repetitive and routinised way (Lawrence and Terlouw, 1993).

Welfare concerns arising from sow stall confinement and the redirected oral and stereotypic behaviour seen has led to them being phased out for all or most of pregnancy in many countries. This has resulted from changes in the law by various jurisdictions (United Kingdom by 1999, EU by 2013, Canada by 2014, and at the time of writing nine individual US states), or from voluntary commitments by commercial companies for future change (e.g., US firm Smithfield by 2017, suppliers of McDonald's restaurants by 2022) or from voluntary bans by industry (New Zealand 2015, Australia 2017). The replacement of stalls by group housing allows for a much greater capacity for movement and normal behaviour, but brings different challenges, the principal one being to deliver each sow her food ration and preventing others from stealing it through aggressive social competition. Sow housing systems that simply drop the feed on the floor are problematic in this regard, and keeping sows in small groups with free-access individual feeding stalls or larger groups with electronic sow feeders and electronic ID are preferable (EUSVC, 1997;

Marchant-Forde, 2009). Electronic sow feeders do still require some careful thought in their installation as to housing design and the feeding time allowed to each sow to avoid problems such as queuing, aggression and vulva biting (Olsson et al., 2011). The time taken by each sow to eat depends on the diet. For example, high-fibre diets take longer to eat (see Sections 7.4 and 7.6 later in this chapter) so may require more feeders for the same number of sows to avoid those problems. Keeping sows in stable groups results in fewer welfare problems such as aggression and lameness than keeping them in dynamic groups in which unfamiliar animals regularly join (Li and Gonyou, 2013).

Allowing sows greater freedom of movement by banning the sow stall addresses a number of significant welfare concerns associated with confinement, but it does not address the underlying hunger resulting from feed restriction, which leads to increased oral behaviours (redirected foraging activity). Research in stalls showed that provision of manipulable material such as straw gives sows a more natural alternative outlet for their foraging activity, leading to reduced bar-biting and sham chewing (Fraser, 1975). An increased food ration will reduce oral behaviours (Terlouw et al., 1991). However, in studies where sows were required to 'work' to access additional food, it is clear that ration-fed dry sows remain highly food-motivated (Lawrence et al., 1988, 1989; Hutson, 1991; Day et al., 1996a,b). But is it possible to increase satiety and reduce hunger without providing additional food energy?

7.3 A basic model of the control of feeding behaviour

In order to better explain the issues facing feed restricted dry sows, and to introduce some terminology, we shall briefly describe a conceptual model of the control feed intake in a normal animal, where food is readily available (Fig. 7.1) simplified from the model of Lawrence and Terlouw (1993). The model could be applied to any wild animal foraging (e.g., a wild boar or feral pig), or an ad libitum-fed farm animal (e.g., a growing pig). We assume that the animal eats to try to achieve a long-term nutritional goal determined by its nutritional needs for growth, maintenance and reproduction. Although referred to by some as a 'set point', this goal is not set, but varies with its age, reproductive status, season, etc. and may vary with type and quantity of food available (D'Eath et al., 2009; Tolkamp and D'Eath, 2016). This nutritional goal has an influence on the internal factors which affect feeding motivation, labelled here as 'hunger'. Feeding motivation is also affected by external factors, opportunities such as a wild animal coming across a rich foraging area, or fresh feed being provided at the same time daily for a farmed animal. Animals will learn to anticipate these opportunities if they conform to a regular pattern, meaning that feeding motivation increases around the time that a meal is expected, or in response to cues predicting food such as the arrival of a stockworker. Anticipation of feed is controlled by a distinct neuroendocrine system (Barbano and Cador, 2006). These internal and external factors combine to produce an overall level of feeding motivation, which if high enough relative to the animal's other priorities

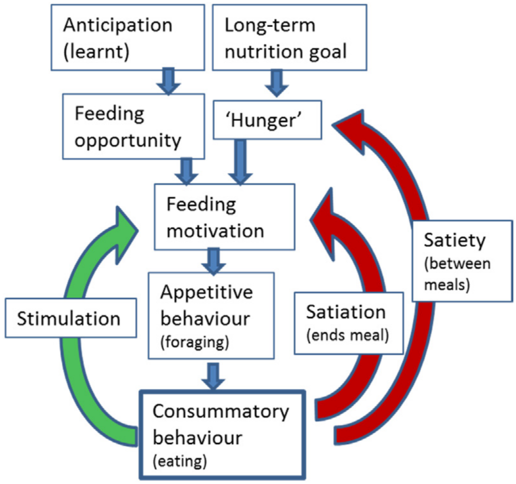

Figure 7.1 Model of the feeding motivation system in a wild pig, or ad libitum-fed growing pig (based on Lawrence and Terlouw, 1993). Blue arrows indicate causal influence of components of the model on each other. Green arrows indicate positive feedback. Red arrows indicate negative feedback.

will result in food-searching behaviour (e.g., hunting, foraging, approaching the feeder) followed by food consumption (eating). These two phases are known as appetitive and consummatory feeding behaviours (Rushen, 1985; Hughes and Duncan, 1988; Jensen and Toates, 1993; Lawrence and Terlouw, 1993), and are controlled by different neuroendocrine systems (Barbano and Cador, 2006), distinct from the system controlling feed anticipation. There are various forms of feedback in the model. As eating begins, positive feedback from sensory food cues such as smell, taste and texture increase feeding motivation, making the animal more likely to continue eating. As eating continues and more food is consumed, signals from the gastrointestinal tract result in negative feedback leading the animal to stop eating (satiation). With feeding motivation satisfied for now, the animal will switch to a different behaviour to satisfy other motivational priorities (e.g., social behaviour, resting, reproductive behaviour, etc.). After a time, as satiety signals from the last meal begin to wear off, hunger will increase again resulting in another bout of foraging which will continue until its successful culmination in eating. In Section 7.6 we will return to this model to explain the situation for sows fed a ration that restricts their energy intake, and given either low or high-fibre diets.

7.4 Reducing hunger/improving satiety in dry sows by changing the diet to include more dietary fibre

Considerable research into sow diets has been done to determine whether hunger can be reduced while still restricting energy intake to limit sow obesity and achieve good production. Much of this work has focused on reducing dietary energy density (energy available in a given mass of food), often by increasing dietary fibre. Conventional diets achieve the goal of restricting energy intake in sows by offering a small quantity of food (quantitative restriction). Alternatively, diets can be formulated which provide a larger quantity of less energy dense food (rationed alternative diets; D'Eath et al., 2009). If energy density of the diet is further reduced, sows can even be fed ad libitum (Ru and Bao, 2004; qualitative restriction, D'Eath et al., 2009). The majority of research in sows has focused on rationed alternative diets.

Water can affect energy density of food, and wet feeding systems are used, but water content of the diet has little effect on satiety. Other than increasing water content, reducing energy density is most easily achieved by replacing energy dense carbohydrate and fat with ingredients high in dietary fibre. In most studies of alternative (high fibre) diets for sows, a greater quantity of a less energy dense alternative diet is provided compared to a more energy dense control (Brouns et al., 1994a; Ramonet et al., 2000a; McGlone and Fullwood, 2001). However in some studies, researchers have specifically set out to test diets with equivalent energy density. In these studies, the reduced energy density effect of adding fibre is deliberately countered by adding additional fat (Whittaker et al., 1999; Sapkota et al., 2016) or sugar (De Leeuw et al., 2004) so that the high fibre and control diets being compared are then fed in portions which are equal in energy, but also equal in mass.

Increasing food volume per unit of energy (with some fibres increasing their volume further as they absorb water and swell in the gut) can stimulate mechanoreceptors in the stomach wall enhancing meal termination (satiation; reviewed by Meunier-Salaün and Bolhuis, 2015). It also slows the gastric emptying rate for the liquid phase of gastric content (Jørgensen et al., 2010), which can promote feelings of 'fullness' that last between meals and make the sow less motivated to try to initiate another meal (satiety; Fig. 7.1). However, depending on the type of fibre, impacts on small intestinal transit differ (Schneeman and Gallaher, 1985).

Dietary fibre can act in a way that increases satiety at various points in the digestive tract, in what is known as the 'satiety cascade' (Howarth et al., 2001; Slavin and Green, 2007; Benelam, 2009; Brownlee, 2011). This includes sensory, cognitive, post-ingestive and post-absorptive elements. These processes begin before ingestion and in the mouth; foods high in dietary fibre smell and taste different, and take longer to eat and chew. Following ingestion, increased viscosity of the gut contents caused by some fibre types affects the process of digestion and gut passage times. Another feature of dietary fibre is that it reduces the absorption of other nutrients, reducing the energy digestibility of a diet (Noblet and Le Goff, 2001), which probably results from physical effects (fibres physically block nutrients from reaching the gut wall) but also because of the increased viscosity, volume of gut contents and interaction with gut microbiota (see later). A combination of these different effects means that adding fibre often results in more of the energy absorbed from a food occurring a longer time after a meal, and further along the gut (Serena et al., 2008).

An important consideration in the post-ingestive phase of the 'satiety cascade' is that dietary fibre digestion differs between pigs and humans. Although fibre is indigestible by mammalian enzymes, pigs' digestion is not limited to mammalian enzymes, as they can 'borrow' the enzymes of their commensal hindgut microflora to digest some forms of fibre by fermentation (Varel and Yen, 1997). In contrast to humans, pigs also harbour a very active microbiota in their ileum, able to completely ferment oligosaccharides, components of the dietary fermentable fibre fraction (Houdijk, 1998). Through fermentation, fermentable fibres, which are primarily non-starch polysaccharides (NSPs), are broken down into short-chain fatty acids (SCFA), including lactate, butyrate, proprionate and acetate (de Leeuw et al., 2008). The energy available from this process is considerable; even in growing pigs, the energy available in the form of SCFA can be up to 30% of the energy requirement for maintenance (Rérat et al., 1987), and it has been suggested that in dry sows this would almost meet energy requirements for maintenance (M. Verstegen, personal communication). Fibre-fed sows show higher levels of SCFA in blood plasma throughout the day than control-fed sows (Jensen et al., 2015).

The timing of energy release from this fermentation process, several hours after a meal, coincides with when blood glucose from digestion of starch and sugars in the stomach is declining. As falling blood glucose is one of the physiological triggers of the next meal, it has been argued that this process is responsible for prolonged satiety. Thus, an additional benefit of switching from glycogenic energy sources to fermentable fibre is the finding that there is reduced diurnal variation of blood plasma glucose and insulin levels (De Leeuw et al., 2004; Serena et al., 2009). When sows are fed a concentrate diet and their hindgut (caecum) is directly infused with fermentable NSP, they show similar levels of activity, and stability of glucose and insulin as sows fed these fibres orally with the same total energy intake (De Leeuw et al., 2005a) suggesting that hindgut fermentation is responsible for these effects of NSP.

The final part of the 'satiety cascade' is the 'post-absorptive' phase, where signals from digestion and from energy stores are compared to the animal's 'long term nutritional goal' (this integration is referred to as 'Hunger' in Fig. 7.1). The vagus nerve is thought to signal the level of glycogen in the liver man (Friedman et al., 2005), and adipose tissue produces leptin, signalling the level of fat stores (Williams et al., 2011). These and other physiological signals are integrated in the brain; the melanocortin system in the arcuate nucleus of the hypothalamus is critical in this integration (Williams et al., 2011; Boswell and Dunn, 2015). This 'long term' aspect of satiety probably remains unaffected by the fibre content of diets (assuming that they contain equal amounts of net energy (NE), i.e., are 'iso-energetic'), unless we assume that providing a high fibre diets alters the 'long term nutritional goal' (D'Eath et al., 2009; Tolkamp and D'Eath, 2016).

7.5 Different types of dietary fibre

So far we have talked in general terms about 'dietary fibre', as though it were one thing, except to say that some kinds of fibre are fermentable in the hindgut of a sow and others are not. A common definition of dietary fibre is 'polysaccharides and remnants of plant materials that are resistant to digestion by mammalian enzymes' (Mertens, 2003; de Leeuw et al., 2008). Dietary fibre defined in this way encompasses a broad class of chemical entities which include lignin and the NSPs (cellulose, hemi-cellulose, fructans and pectins). However, it may also be relevant to include non-digestible oligosaccharides and resistant starch (Van Soest et al., 1991; de Leeuw et al., 2008).

Dietary fibre is quite difficult to measure in the laboratory. Various methods exist, with each method detecting with varying degrees of precision a different subset of fibre types (Fig. 7.2). The Weende method to measure 'crude fibre' (cellulose and lignin) is over a 100 years old (Bach Knudsen, 2001) and remains in use. However, it has been largely superseded by the Van Soest method (1967; Fig. 7.2), which was further updated Van Soest et al. (1991) to be more suitable for monogastrics. The best methodology continues to be debated, refined and improved (Mertens, 2003; Cummings and Stephen, 2007). Unfortunately, the diversity of methods means that different scientific studies of sow diets often report different analytical methods when describing the complete diets used. This complicates matters when attempting to compare the behavioural and physiological effects of different dietary ingredients that differ in some aspect of 'dietary fibre'.

In addition to their chemical class (e.g., NSP), analytical class (e.g., NDF) and fermentability, fibre types can be further classified in terms of their physicochemical properties including their solubility or water holding capacity (Day et al., 1996a) and their viscosity. These aspects have considerable influence on the way in which sows eat and digest them, and the effects they have as they pass through the

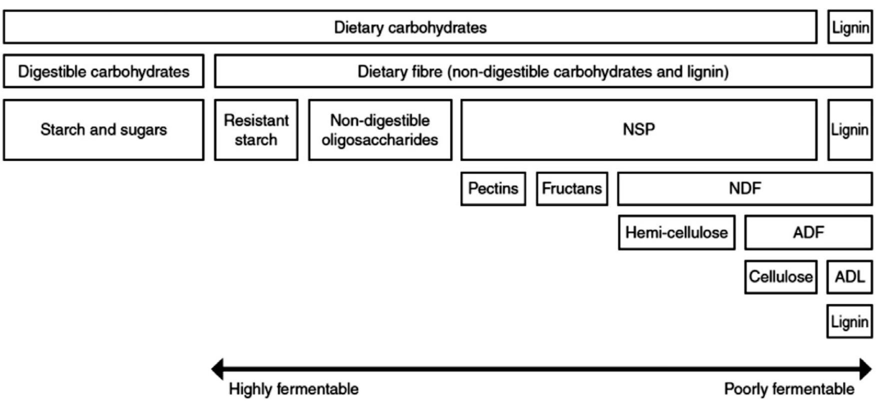

Figure 7.2 Schematic representation of different classes of carbohydrate and fibre. Also shown are the chemical entities identified by Van Soest's analysis method: *NDF*, neutral-detergent fibre; *ADF*, acid-detergent fibre; *ADL*, acid-detergent lignin. The approximate ease of fermentation of different fibre types is shown as a continuum underneath. Digestible carbohydrates (starches and sugars) are digested without the need for fermentation. *Source*: Reproduced with permission from de Leeuw et al. (2008).

gut (Bach Knudsen, 2001; Souza da Silva et al., 2012). Physiochemical characteristics are rarely quantified in reports of sow diets, with a few exceptions (Serena et al., 2008; Jørgensen et al., 2010; Jensen et al., 2012).

Soluble fibres generally have a high capacity to absorb and bind to water, often forming a gel and swelling in the process. When consumed, this property increases the volume and viscosity of the gut contents in the stomach and small intestine, but upon reaching the large intestine, soluble fibres are often broken down by fermentation (Bach Knudsen, 2001). Insoluble fibres do not absorb water, are indigestible (in monogastrics such as pigs) so pass through the gut largely unaffected and have their greatest effect in the large intestine, increasing faecal volume. They are usually less fermentable (Blackwood et al., 2000; Serena et al., 2008). Within the fermentable fibres, there are also differences in fermentation characteristics: the type of SCFAs that are mainly produced (acetate, butyrate and propionate) and the rate of fermentation (Souza da Silva, 2013).

Typical feed ingredients used in dry sow diets by industry and by various experiments into dietary fibre are shown in Table 7.1.

7.6 Behavioural and physiological changes seen in sows given high fibre diets

Increasing the total feed energy available can affect satiety as evidenced by reduced activity and oral behaviours (Terlouw et al., 1991) and feed motivation (Lawrence et al., 1988). So when comparing diets that differ in fibre content, it is important to accurately know the energy value of diets, so that feed quantity can be adjusted to provide equivalent energy intake, thereby allowing a fair comparison of the effect of fibre. Some definitions are needed before we consider this further. Gross energy (GE) in any material including food is the total chemical energy released if it is burned in a bomb calorimeter. But not all this energy is available to an animal because indigestible components are lost in faeces. What remains is digestible energy (DE), and once energy losses in urine are considered that leaves metabolisable energy (ME), some of which is lost as heat, leaving NE for production functions and maintenance. Previously, we had recommended comparing diets that were equivalent (iso-energetic) in ME or NE rather than GE or DE (D'Eath et al., 2009).

However, iso-energetic feeding is often difficult to achieve in practice for a number of reasons. It can be particularly difficult to predict the DE accurately in advance, because the energy available from fermentation (e.g., van der Peet-Schwering et al., 2003) is dependent on sows' age, breed, diversity of intestinal flora and even the physical form of the feed (Le Goff and Noblet, 2001).

Changes in behavioural activity as a result of certain diets can affect energy expenditure, and finally fibre diets can produce greater levels of metabolic heat from fermentation (heat increment of feeding; Lee and Close, 1987) which may be useful to the sow in cold weather and less useful in warm weather, again affecting

Table 7.1 **Characteristics of different feedstuffs used in dry sow diet studies. A qualitative statement of fermentability is given for fibres and resistant starch. Cereals and meals are digestible by the action of the pigs own enzymes in the stomach and intestine**

Class of feedstuff	Name	Crude fibre (g/kg DM)[a]	Dietary fibre (g/kg DM)[b]	Soluble NCP (g/kg DM)[c]	Insoluble NCP (g/kg DM)[c]	Ferment-ability[d]	Primary fibre type[d]	References to sow diet experiments which made use of this ingredient
Cereals	Wheat	25	138	19	62	Digestible	–	Often used in control diets
	Maize/corn	28	108	25	38	Digestible	–	Often used in control diets
	Barley	46	221	50	64	Digestible	–	Often used in control diets
	Oats					Digestible		Rushen et al. (1999)
Meals	Soybean meal	72	233	63	92	Digestible	–	Control diet (Robert et al., 1993; McGlone and Fullwood 2001; Holt et al., 2006; De Decker et al., 2014; Sapkota et al., 2016)
Fibres	Maize/corn gluten feed	73	25	34	242	Low	Insoluble	Ramonet et al. (2000b)
	Wheat middlings/ wheat feed	75–110	201	12	227	Low	Insoluble	De Decker et al. (2014), Hazzledine (2014)
	Sunflower meal (dehulled)	103						Ramonet et al. (2000b)
	Wheat bran	100	449	29–38	243–273	Low	Insoluble	Matte et al. (1994), Brouns et al. (1995), Ramonet et al. (2000a), Wilfart et al. (2007)
	Rice bran	102						Brouns et al. (1995)
	Citrus pulp	135						Day et al. (1996a)
	Sugar beet pulp	210	814	290	207	Very high	Soluble	Brouns et al. (1995), Brouns et al. (1994b), Whittaker et al. (1999), Ramonet et al. (2000a), Zonderland et al. (2004), Jørgensen et al. (2010), McGlone and Fullwood (2001), Yde et al. (2011), Sapkota et al. (2016)

(*Continued*)

Table 7.1 **(Continued)**

Class of feedstuff	Name	Crude fibre (g/kg DM)[a]	Dietary fibre (g/kg DM)[b]	Soluble NCP (g/kg DM)[c]	Insoluble NCP (g/kg DM)[c]	Ferment-ability[d]	Primary fibre type[d]	References to sow diet experiments which made use of this ingredient
	Sugar beet pulp silage	214				Very high	Soluble	Rijnen et al. (2003)
	Maize/corn silage	236						Jensen and Pedersen (2007), CIWF Food Business (2013)
	Maize/corn cobs	349						Matte et al. (1994)
	Soybean hulls	391		84	755	High	Soluble	Zonderland et al. (2004), Stewart et al. (2011), De Decker et al. (2014), Sapkota et al. (2016)
	Wheat straw	382		5	710	None		Lawrence et al. (1989), Veum et al. (2009)
	Barley straw	405				None		Brouns et al. (1995)
	Pectin						Insoluble	Jørgensen et al. (2010), Yde et al. (2011)
	Oat hulls	300	653	13	295		Insoluble	Brouns et al. (1995), Rushen et al. (1999), Bergeron et al. (2000), Robert et al. (2002)
	Alfafa	286		42	524			Bergeron et al. (2000), Robert et al. (2002)
	Potato pulp						Soluble	Yde et al. (2011), Jensen et al. (2015), Jensen et al. (2012)
Resistant	Resistant maltodextrin					High		Sapkota et al. (2016)
Starch	Retrograded tapioca starch					High		Souza da Silva et al. (2013)
	Native potato starch					High		Souza da Silva et al. (2012)

[a]Crude fibre from Weende analysis (cellulose and lignin) from Noblet and Le Goff (2001) and feedipedia.org.
[b]NSPs plus lignin from Bach Knudsen (1997).
[c]NCP is non-cellulosic poly-saccharides. From Reese et al. (2008), Jaworski et al. (2015), Jha and Berrocoso (2015).
[d]From Meunier-Salaün and Bolhuis (2015), de Leeuw et al. (2008) and cited refs. Day et al. (1996a,b), Lawrence et al. (1989), Jensen and Pedersen (2007) and Wilfart et al. (2007) are references from growing pigs or boars which are included because they are relevant to the discussion.

energy balance. Another issue is that sows also eat materials such as straw provided as bedding (Fraser, 1975) or in racks as a foraging/enrichment material (Stewart et al., 2008, 2011). Fraser (1975) found that sows consumed 1 kg of straw a day, more easily if it was chopped and in their trough, but even if it was on the floor.

To check that iso-energetic feeding has been successful, one possibility would be to weigh sows before and after a feeding trial. However, weight gain of sows can result from increased weight of the GI tract (which can increases in size in response to fibre feeding), and the food and water it contains. Pregnancy is also a complicating factor, due to the presence of potentially variable numbers and weights of piglets, placenta and associated tissues in the sows' uterus. For these reasons, it may be better to rely on backfat depth measurement as an indication of energy status rather than live weight, which in any event appears to be a better predictor of offspring growth (Amdi et al., 2014).

With these methodological difficulties in mind, a number of studies have shown common changes in sows fed fibre: various behavioural and physiological changes reliably occur when high-fibre diets are compared to conventional concentrate diets (reviewed by de Leeuw et al., 2008; D'Eath et al., 2009; Meunier-Salaün and Bolhuis, 2015). Many of these changes are seen to a greater and longer-lasting extent with diets rich in fermentable, soluble fibre sources such as sugar beet pulp or potato pulp, whilst insoluble fibre sources such as pectin, wheat bran or oat hulls typically have a lesser, or shorter lasting effect (Danielsen and Vestergaard, 2001; Jørgensen et al., 2010; Souza da Silva et al., 2012). Recent research into feeds high in resistant starch (which is highly fermentable) has shown that they produce many of the same effects as fermentable fibre (Souza da Silva et al., 2012, 2013; Sapkota et al., 2016). The various changes in behaviour and physiology that occur in sows fed iso-energetic quantities of fibre (F) in contrast to conventionally feed-restricted sows (C) are summarised later, and are illustrated in Figs. 7.3−7.5.

7.6.1 Pre-meal

Increasing fibre results in reduced arousal and anticipation of food, as indicated both by reduced behavioural agitation (standing, active) and by a reduced heart rate (Robert et al., 2002) and cortisol (Rushen et al., 1999) relative to control sows (Fig. 7.3). This could be interpreted in a positive way. It could suggest that fibre-fed sows are less hungry pre-meal, and in group-housed sows where there is the possibility of competition (e.g., in floor feeding, Whittaker et al., 1999; or in open stalls) there is a greater urgency to finish a concentrate ration, while the fibre diet takes longer to eat. Or it could be interpreted in a negative way. We know that sows prefer concentrate over high-fibre diets when freely offered both (Guillemet et al., 2007a), in fact this is a widespread finding that more energy dense foods are preferred by animals (Mela and Rogers, 1998). As such, the reduced arousal of sows pre-meal could reflect their lack of anticipation and excitement about receiving a less attractive diet, albeit in a larger quantity (Spruijt et al., 2001).

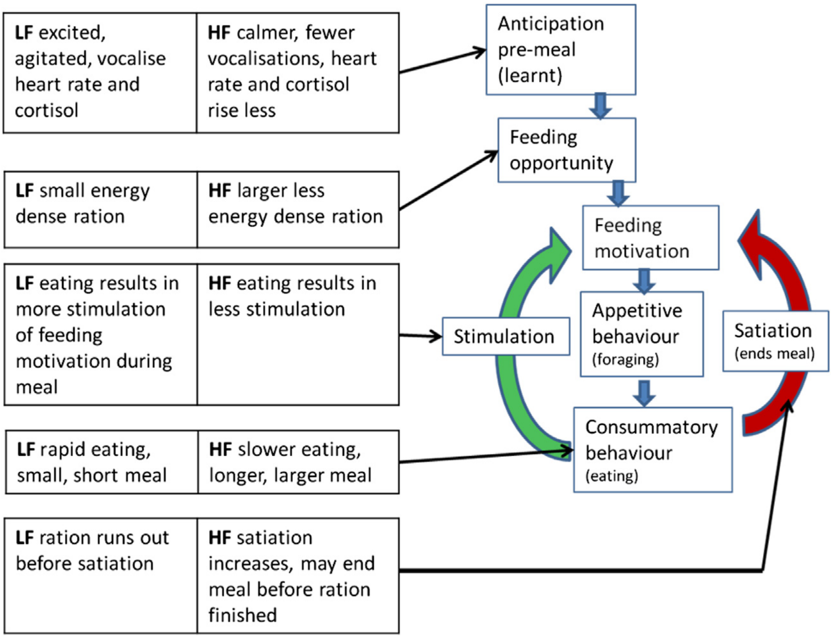

Figure 7.3 Pre-meal and during a meal: a diagram (based on Fig. 7.1) summarising how elements of the feeding motivation system are affected by feeding a sow an iso-energetic high-fibre diet (HF) compared to a low-fibre diet (LF) at this time.

7.6.2 During a meal

Sows consume all types of high-fibre foods more slowly, resulting in a longer meal (Rushen et al., 1999; Ramonet et al., 1999; Bergeron et al., 2000; Rijnen et al., 2003) or, where there is more than one meal, in a longer total time spent eating (Fig. 7.3). This effect occurs even when the fibre and control diets do not differ in weight or volume. One possibility is that a slower rate of eating may be associated with increased saliva production in the oral cavity in response to the water holding properties of the fibres. These changes in meal duration occur regardless of the fibre type (de Leeuw et al., 2008). It seems likely that slower eating of a less energy dense food would have a reduced short-term positive feedback on feeding motivation, which in concentrate-fed sows results in high levels of redirected oral behaviours after the food is exhausted (Terlouw et al., 1991; and see Section 7.6.3 later). Depending on the quantity of food and its fibre content, sows may voluntarily end a meal before the food is exhausted, resulting in a more natural feeding pattern (Brouns et al., 1994a).

7.6.3 Post-meal

Fig. 7.4 summarises the effect of fibre on motivation, behaviour and physiology of sows post-meal. High-fibre diets result in a reduction in dry sow activity and an

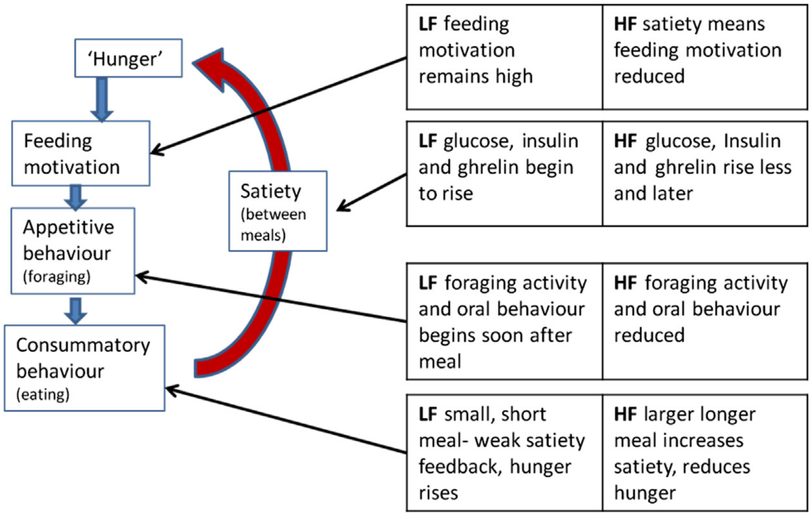

Figure 7.4 Post-meal: a diagram (based on Fig. 7.1) summarising how elements of the feeding motivation system are affected by feeding a sow a high-fibre diet (HF, and in particular a fermentable fibre diet) compared to a conventional low-fibre diet (LF) at this time.

increase in resting compared to low-fibre control diets (Zonderland et al., 2004; Brouns et al., 1994a; Danielsen and Vestergaard, 2001). High-fibre diets also result in a reduction in various oral behaviours including 'abnormal' or redirected foraging such as sham chewing (Zonderland et al., 2004; De Leeuw et al., 2005b), manipulating or biting at bars, floor or troughs (Jensen et al., 2015; Sapkota et al., 2016), or directed towards the drinker (Robert et al., 1993; Whittaker et al., 1999; Jensen et al., 2015), but also in foraging directed at more natural substrates such as straw bedding (Brouns et al., 1994a). Where sows fed control diets are compared with sows fed an equivalent total amount of energy in a high-fibre diet, there is some variation between studies as to whether the total amount of oral behaviours reduces (Brouns et al., 1994a; De Leeuw et al., 2005b) or remains at a similar level (Ramonet et al., 1999; Whittaker et al., 1998, 1999). Physiological changes also occur: plasma concentrations of the 'empty stomach' hormone ghrelin are reduced in fibre-fed sows soon after a meal, and insulin is also lower at this time (Jensen et al., 2015). Post-meal increases in glucose and insulin were delayed and smaller following a high-fibre meal (Rushen et al., 1999; Farmer et al., 2002; Quesnel et al., 2009). These physiological effects of fibre which occur soon after a meal are not affected by the specific type of fibre used (De Leeuw et al., 2008).

7.6.4 *Some hours post-meal/between meals*

Fig. 7.5 summarises the effect of diets high in fermentable fibre on motivation, behaviour and physiology of sows several hours after a meal. Non-fermentable

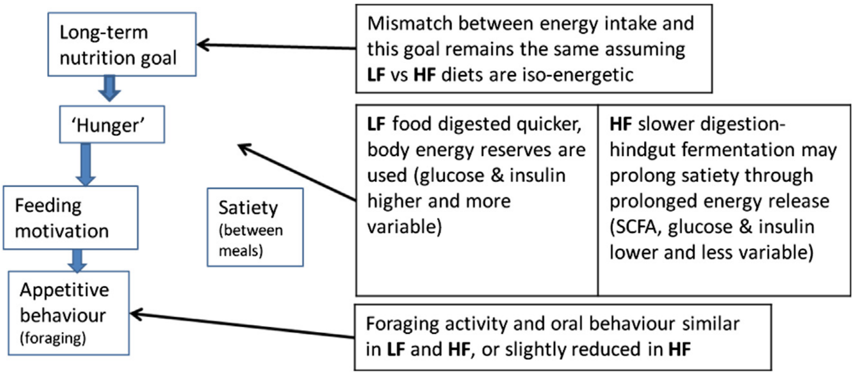

Figure 7.5 Some hours post-meal or between meals: a diagram (based on Fig. 7.1) summarising how elements of the feeding motivation system are affected by feeding a sow a high fermentable fibre diet (HF) compared to a conventional low-fibre diet (LF) at this time.

fibres do not have a noticeable effect on sows at this time. Behavioural changes include reduced activity (Jørgensen et al., 2010; De Leeuw et al., 2005b), reduced redirected oral behaviour such as manipulation of pen fixtures (Whittaker et al., 1998), less time manipulating straw (Whittaker et al., 1998) and fewer posture changes (De Leeuw et al., 2004). Fibre feeding reduces blood plasma glucose and insulin concentrations, delaying when they peak and reducing their variability (De Leeuw et al., 2004, 2005a; Serena et al., 2009). This probably reflects the availability of other energy substrates such as SCFA through fermentation, reducing the need for the sow to use body energy stores of glycogen to produce glucose (Serena et al., 2009; Jensen et al., 2015). These more prolonged changes in behaviour and physiology are more evident when soluble and fermentable fibres such as sugar beet pulp (Whittaker et al., 1998; De Leeuw et al., 2004; Jørgensen et al., 2010), potato pulp (Jørgensen et al., 2010) or from a range of fermentable sources (De Leeuw et al., 2005b) are fed (De Leeuw et al., 2008).

7.6.5 Motivation for additional feed

Animal welfare is determined by the (hidden) subjective emotional mental states such as hunger, fear, excitement or boredom. We assume that animals experience these states in a way that is analogous to our experience of them and that these states matter to the animals experiencing them. Motivational tests can reveal which resources or situations animals are willing to work to access or to avoid, and as such can be a powerful tool in the assessment of animal welfare (Dawkins, 2006; Kirkden and Pajor, 2006). If high-fibre diets reduce hunger and improve satiety in sows, we would expect that fibre-fed sows' motivation to forage and to eat would be reduced. A variety of different studies over the years have looked at feeding motivation by training pigs to perform a repeated task (such as pressing a panel, or turning a wheel, or walking some distance) to receive a food reward.

These methods have been validated by showing that responding in such tasks increases when animals are feed restricted (Lawrence et al., 1988, 1989; Lawrence and Illius, 1989; Robert et al., 1997). Typically, the willingness to work is tested by progressively increasing the number of responses needed to get a food reward as the task goes on (known as a progressive ratio), and recording at what ratio the sow gives up, or how many rewards she obtains within a limited time.

These techniques have been applied to the question of high-fibre diets by comparing the motivation for additional feed in growing pigs (Lawrence et al., 1989; Day et al., 1996a) or sows (Robert et al., 1997, 2002; Bergeron et al., 2000; Ramonet et al., 2000a; Jensen et al., 2012, 2015; Souza da Silva et al., 2012, 2013) fed on different kinds of fibre diets and compared to a low-fibre control.

Various studies have compared the motivation to access food rewards of sows fed on high or low-fibre diets, with the same total energy intake (DE or ME) (Lawrence et al., 1989; Bergeron et al., 2000; Ramonet et al., 2000a; Souza da Silva et al., 2013) or when diets had iso-energetic NE (Jensen et al., 2015). In all cases there was no difference in motivation. However, the interpretation of these experiments is complicated by the difficulty in designing diets which compare like with like by feeding sows equivalent energy (see discussion in D'Eath et al., 2009). For example, Day et al. (1996a) scaled the DE available per kg of live weight in a study of male growing pigs, and did find an effect of fibre on the operant response for a sound that pigs had learnt to associate with food (second-order schedule).

Recent experiments by Souza da Silva et al. (2012, 2013) did not use iso-energetic rations, having lower levels of ME in the fibre diets than in the control diet. However, they found similar levels of responding in food motivation tasks for control and fibre diets, and argued that the satiating effect of fibre compensated for the reduced ME. Even then, the effects are relatively small. Another interesting aspect of the work of Souza da Silva et al. (2012, 2013) was that they used two different motivational tests: A test of consummatory motivation where pigs had to root a wheel next to a food trough to receive food rewards, and a test of appetitive motivation where pigs had to walk around a runway to earn a food reward. Different fibre types affected the two tests differently: lignocellulose reduced wheel rooting for food rewards while pectin increased it (Souza da Silva et al., 2012), but wheel rooting was not affected by fibres with different fermentation characteristics (Souza da Silva et al., 2013). Motivation to walk for a food reward was increased by lignocellulose or pectin, but reduced by modified tapioca starch (resistant starch; Souza da Silva et al., 2013). These experiments used adult non-pregnant sows, avoiding the problem that sows become less active in late pregnancy.

An additional difficulty with food-rewarded motivation tests is the question of what food reward sows should receive during the test, and its possible effect on the results. For example, in the experiments of Robert et al. (1997, 2002), fibre-fed sows appeared less motivated for food; they worked less for food rewards in an operant task than control-fed sows. However, sows in these experiments were rewarded with a standard weight of their own usual diet. This means that the fibre-fed sows' rewards each contained less energy, which may explain why they were less motivated to work for them. All other sow feeding motivation studies we have cited used a standardised type and quantity of reward across all feeding treatments and most found no effect of diet on responding.

The use of food rewards in these operant tasks may in itself be a problem. Delivery of rewards is likely to increase food motivation in the short-term due to positive feedback (see Fig. 7.1; Lawrence and Terlouw, 1993), which could affect the outcome of the test. To avoid this problem, Day et al. (1996b) used a second-order schedule, where pigs were trained to associate a sound with food delivery, and their food motivation was then tested using this sound as the only reward. Day et al. (1996a) found that responding post-meal was reduced with increasing fibre (citrus pulp which has a high water holding capacity), although this effect was sufficiently short-lived that it was no longer seen prior to the next meal.

In summary, fibre-fed sows show a variety of changes in their home pen behaviour and physiology: reduced arousal pre-meal, increased feeding time, reduced self-directed or redirected oral behaviour. When fermentable fibres are fed, they also show reduced activity in most studies and more stable glucose and insulin over the day. However, food motivation measured in food-rewarded tasks does not provide support for the idea that fibre-fed sows are more satiated. Most studies have found that they 'work' for additional food at the same level as control-fed sows, although some studies show reduced food motivation for a period of time after a high-fibre meal.

7.7 Does dietary fibre increase satiety and improve welfare in dry sows?

We have discussed the known physiological effects of fibre on the digestive tract, and the various changes in behaviour and physiology that occur over a number of hours after a meal. Taken together, it has been argued that these changes, particularly when soluble fermentable fibres are fed, reflect an improvement in satiety and therefore of sow welfare (de Leeuw et al., 2008; Meunier-Salaün and Bolhuis, 2015).

Others have argued that fibre does not really improve welfare as 'metabolic hunger' defined as 'a mismatch between an animal's current state of energy balance and their physiological 'goal' (Savory and Lariviere, 2000) remains unfulfilled (Dailey and McGlone, 1997; McGlone and Fullwood, 2001). Referring back to Fig. 7.1, in effect these authors are arguing that the long-term nutritional goal has a much larger influence on 'hunger' than satiety signals. For them, the temporary cessation of feeding with high-fibre diets is due to the physical constraints of consuming fibre (gut fill, water absorption, slow digestion), which have no impact on the sensation of hunger. Under this scenario, if the only thing that matters is whether the nutritional goal is met by any means, then any iso-energetic diet will be equivalent for welfare, because the feedback from a comparison of the 'set point' with the actual state of growth and long-term energy stores will be the same. One argument in support of this is that in many studies 'total oral' behaviours and activity levels are unchanged with iso-energetic alternative diets (Dailey and McGlone, 1997). However, some studies do find that these change. For example, Brouns et al. (1994a) found a marked reduction in total oral behaviours and activity when comparing iso-energetic control and 50% sugar beet pulp diets. Another argument in support of this is the finding that feeding motivation is unaffected or only reduced for a while after a meal by fibre feeding, although there are various criticisms that can be levelled at food-rewarded tests of feeding motivation (see Section 7.6.5 earlier).

In our view, this 'metabolic hunger' argument places too much emphasis on the 'long-term nutritional goal' of the sow. We support the view that the sensation of 'hunger' results from a balance between the long-term nutritional goal and the various signals which make up the 'satiety cascade' (Brownlee, 2011) discussed above. High-fibre diets prolong the consummatory phase (duration of eating), and fermentable fibres in particular promote physiological signals of satiety which provide negative feedback over at least part of the day to reduce hunger and feeding motivation (Figs. 7.3–7.5).

7.8 Does access to foraging substrates improve welfare in sows?

Earlier we introduced the concept of appetitive and consummatory phases of feeding behaviour (Fig. 7.1). De Leeuw (2004) described the satisfaction of these two aspects of feeding motivation as being distinct, referring to 'behavioural satiety' and the second as 'nutritional satiety'. He argued that providing an appropriate outlet such as straw bedding, soil or other loose materials for the normal appetitive feeding behaviour (foraging, rooting, sniffing, etc.) of sows would mean that their oral behaviours were more natural and varied, which might as such promote 'behavioural satiety' and thus sow welfare.

In addition to thinking about foraging behaviours as the appetitive phase of feeding, there is also evidence that pigs are motivated to explore their environment as an end in itself, independent from the goal of finding food. Pigs are motivated to investigate and explore their environment by moving around and sniffing, nosing, rooting and chewing at materials (Tuyttens, 2005), and this occurs to some extent even in satiated growing pigs (Jensen et al., 1993) or sows (Zonderland et al., 2004). In growing pigs, the absence of these materials can lead to undesirable redirected behaviours such as ear, flank or tail-biting. This exploratory behaviour is probably only indirectly linked with feeding; the ultimate function of exploratory behaviour is probably that animals will encounter, sample and learn about new food sources in their environment, and then to continuously gather up to date information about known food sources (Day et al., 1998; Studnitz et al., 2007). Loose materials such as straw (when provided in sufficient quantities) provides other opportunities to express behaviours, as it can be carried and arranged for nesting, creating a comfortable lying area and improving thermal comfort (Tuyttens, 2005).

There are various lines of evidence suggesting that pigs are motivated to perform exploratory behaviours. Ad libitum-fed pigs still spend considerable time in investigative behaviour, and prefer to forage for hidden food even when food is offered 'for free' (contra-freeloading, de Jonge et al., 2008). Sows that are prevented from rooting by nose ringing still show other forms of exploratory behaviour (Studnitz et al., 2003), although rooting is preferred once nose rings are removed.

There is an interaction between motivation to forage and to explore (Day et al., 1998). Pigs initially investigate two similar novel objects to the same degree, but over repeated trials they spend more time with the one exuding a sugar solution than the one exuding water (Day et al., 1996c). The presence of edible components within a manipulable material increased pigs' motivation to access (Jensen and Pedersen, 2007) and sustain the use of (Van de Weerd et al., 2003) that material.

In dry sows, access to foraging materials (such as straw) can reduce exploratory behaviour directed at bars and other pen fixtures by providing a more 'natural' outlet for investigatory/foraging behaviour (Spoolder et al., 1995). However, some studies have found that feeding-related oral behaviours such as sham chewing are not affected by straw (Stewart et al., 2008), unless high-fibre diets are provided as well (Stewart et al., 2011). The welfare benefit of switching the target of oral behaviours from bars to straw has been disputed (Dailey and McGlone, 1997), for example Whittaker et al. (1998) stated that 'it is unclear to what extent welfare is improved by exchanging excessive pen component manipulation with the excessive manipulation of straw'.

As well as possible benefits to welfare, a recent meta-analysis suggested that there may be production benefits to providing sows with manipulable materials. Sows kept in systems with solid floors, which implies some form of loose bedding material, had larger litters (numbers born alive) than sows kept on part- or fully-slatted floors (Douglas et al., 2014).

7.9 Fibre in typical industry diets

The foregoing discussion has suggested that the addition of fibre to the diet, particularly in a fermentable form (soluble NSP or resistant starch), and provision of foraging substrates can have benefits for sow welfare by improving satiety and providing a natural outlet for foraging behaviour. In this section we consider the extent to which these findings have been implemented by industry, particularly in the light of EU Council Directive 2008/120/EC (2008). This directive requires that 'Member States shall ensure that all dry pregnant sows and gilts, in order to satisfy their hunger and given the need to chew, are given a sufficient quantity of bulky or high-fibre food as well as high-energy food', and has been a requirement since 2001 (The Council of The European Union, 2001). However, there is a lack of specific guidance on the quantity or type of 'bulky or high-fibre food' required (CIWF, 2009), and whether straw bedding is assumed to count as a dietary supplement also. The same EU directive also requires that growing pigs and sows have 'permanent access to a sufficient quantity of material to enable proper investigation and manipulation activities, such as straw, hay, wood, sawdust, mushroom compost, peat or a mixture of such, which does not compromise the health of the animals'.

A 2001 survey (as part of an EU EFSA, 2007 report) found that the proportion of sows with access to diets high in crude fibre (see Section 7.5) and/or foraging material varied a lot between different EU countries. Among EU member states, The Netherlands appears to offer the most specific guidance on fibre diets for sows. De Leeuw (2004) presents a table from the Pig Farmer's Animal Welfare helpdesk (1998) which suggests a variety of options: 100 g a day of hay or straw, 250 g a day of various supplementary roughages, or where fibre is part of the ingredients for a pelleted diet: 140 g/kg of crude fibre or 340 g of residual organic matter (NSPs). De Leeuw et al. (2005a) state that 340 g/kg of NSP is compulsory in The Netherlands. These guidelines are still followed, and an example Dutch industry dry sow diet has 10% crude fibre, containing fibre from various sources: 15% wheat middlings, 11% soya hulls, 4% palm kernels and 7% sugar beet pulp (Carola van der Peet-Schwering, pers. comm.). Although there is fibre in the diet, the use of bedding straw is unusual in The Netherlands.

In Germany, dry sow diets normally contain a fair amount of fibre. For example Reckmann et al. (2013) assume 18% wheat bran, and Reckmann et al. (2016) assume 17% wheat bran and 10% sugar beet pulp in their modelling of 'standard' dry sow diets.

In Ireland, typical dry sow diets are low in fibre, containing as little as 4.5% crude fibre, and no 'high fibre' ingredients. Access to straw bedding (or in racks) is also unusual (O'Driscoll and Lawlor, pers. comm.).

In the United Kingdom, almost half of dry sows are outdoors; DEFRA (2009) figures for pig farms in England suggest that 41% of dry sows were outdoors, 48% of sows were in indoor straw-based systems, with the remaining 11% indoors in slurry-based systems. Rutherford et al. (in preparation) sent surveys in 2012/13 to 580 UK pig farmers. Of 153 farms that replied, 15% provided no additional fibre, while the majority (75%) provided fibre in the form of straw bedding, some of which (it is assumed) is eaten. Industry diets in the United Kingdom typically contain some additional fibre because they include around 30% wheat feed, with typical crude fibre and NDF levels of 110 and 435 g/kg DM, respectively (Hazzledine, 2014). Wheat feed is a byproduct of flour milling, containing wheat bran, endosperm and starch (also referred to as wheat middlings). Edwards (2002) lists feed ingredients suitable for organic pig producers, including a variety of fibres and forages (including byproducts, root crops, grass and silage), and describes a typical dry sow diet with 25% wheat feed. However, wheat feed is relatively low in fibre compared to other fibre ingredients (Table 7.1), containing a fair amount of starch, and the fibre is mainly insoluble so cannot be fermented or digested by sows. Even taken in combination with the consumption of straw bedding by sows that have it, it appears that most sows in the United Kingdom have very little soluble or fermentable fibre as part of their diets.

In the United States, dry sow 'example diets' given to accompany the National Swine Nutrition Guide produced by the US Pork Center of Excellence (Reese et al.,

2010) include two examples. One is a low-fibre corn and soybean meal based diet, and the other has soybean hulls at 21.6% inclusion (soybean hulls are a source of soluble and fermentable fibre), and a number of producers are using diets with various dietary fibre sources.

In summary, although there are probably behavioural benefits to feeding more of any kind of fibre, we saw in Section 7.6 that many of the behavioural and physiological changes which may indicate improved satiety over a prolonged period occur when highly fermentable fibres or resistant starch are used at high inclusion rates. Depending on the country and system, industry diets typically contain lower levels of fibre, from mixed or mainly insoluble sources. The use (or not) of foraging material such as straw bedding, or straw in racks also varies between farms, systems and countries. This would indicate that there is room for improvement of dry sow welfare, especially through increasing the use of fermentable fibre or resistant starch, but also through increased provision of foraging materials.

7.10 Sow diet effects on social behaviour

Group-housed sows form a dominance hierarchy, and there is a risk that dominant sows try to bully others in order to get access to their food ration. Aggression can vary in a way which depends on an interaction between the housing type, space allowance, amount of social mixing, the feeding system (feed on the floor, in troughs, or from an electronic sow feeder) and the diet, including the type and quantity of fibre, the form of the feed and the timing and frequency of feeding (Marchant-Forde, 2009; Hemsworth et al., 2015).

For example, the level of aggression in group-housed sows can depend on the feeding system, diet and bedding. In a floor-feeding system, a 2×2 experiment with high (60% sugar beet pulp) or low-fibre iso-energetic rations; and straw bedding or not, aggression was increased with straw bedding (Whittaker et al., 1999). This was thought to be because food became scattered amongst the straw and was harder to find, leading to prolonged food-searching and feeding, and this then created more opportunities for aggressive displacement. In a study by Sapkota et al. (2016), group-housed sows fed in free-access stalls were given one of three high-fibre diets (sugar beet pulp, soy hulls or resistant starch added to a basal diet) or a low-fibre control. They found that control sows had the most skin lesions while resistant starch-fed sows had the least, 24 h after mixing into a new group. Similarly, Danielsen and Vestergaard (2001) found that diets high in sugar beet pulp (soluble fermentable fibre) led to reduced aggression in dry sows, in comparison to a low-fibre control diet or a diet containing insoluble fibre from various sources.

Finally, it has been reported that vulva biting was reduced in fibre-fed sows (Whittaker et al., 1999; De Decker et al., 2014). This behaviour is not thought to be conventional 'social' aggression, but may relate to feed competition (Van Putten and Van de Burgwal, 1990).

7.11 Sow diet effects on gut health

Dietary fibre influences the type and number of commensal micro-organisms in the gut, and this is particularly true of fermentable fibres (Lee and Close, 1987; Varel and Yen, 1997; Jha and Berrocoso, 2015). Some types of fibre may encourage proliferation of healthy bacteria, which can have a probiotic effect, improving gut health, and contribute towards reducing the use of growth-promoting antibiotics in pig feed.

A report by the EFSA Panel on Animal Health and Welfare (EFSA, 2007) suggested that high-fibre feeds could help reduce gastric ulcers in sows. It is important to realise though that the relationship between fibre and ulcers is indirect. The form of the diet is more important than fibre content: feeding finely ground pelleted feeds increase gastric ulceration compared to coarsely-ground meal feeds (Maxson et al., 1968; Lee and Close, 1987; Friendship, 2004; Jørgensen and Jensen, 2004), probably because finely ground feeds result in a more fluid stomach contents (Canibe et al., 2005). If dietary fibre is processed into a pelleted diet it may have little effect on gastric ulcers; cellulose extract protects against ulcers, but not if it is finely ground (Henry, 1970). However, if farmers provide supplementary fibre in its natural form, e.g., whole potatoes, maize silage, etc., or provide access to straw bedding, this may protect against ulcers. In finishing pigs, permanent access to straw bedding reduces gastric ulcers (Nielsen and Ingvartsen, 2000; Herskin et al., 2016) presumably because pigs eat the straw. Whether or not ulcer incidence is related to satiety, and the effects on ulcers of feeding system and housing, remain to be established.

7.12 Number and timing of meals

Dry sows are typically fed their entire ration once a day in the morning, or may have the same ration split into morning and afternoon meals. Twice a day feeding (compared to once a day) reduces feeding motivation in the evening and before the morning meal. Furthermore, twice a day feeding reduced diurnal variation in non-esterified fatty acids (NEFA; an energy substrate released from stored body fat) in the blood plasma of sows fed on sugar beet or potato pulp diets, and reduced the levels of plasma SCFA for sows fed a sugar beet diet (Jensen et al., 2012).

Stereotypic oral behaviour and vocalisations before meals, and drinking, licking the empty feeder and oral stereotypies after meals were more frequent when two meals were fed rather than one (Robert et al., 2002). Holt et al. (2006) found that sows spent longer with their heads in the feeder (recorded as ‘feeding’) in twice-fed sows compared to once-fed sows, and put this down to post-meal licking and nosing of the empty feeder. This increase in oral activity around and after feeding time is perhaps not surprising since it is known that providing a small meal facilitates the immediate post-meal performance of stereotypy in rationed dry sows (Terlouw et al., 1993). This is thought to be because ingestion of food causes short-term positive feedback to increase feeding motivation (Figs. 7.3 and 7.4), but the small rationed meal provided results in only a small negative feedback to feeding motivation (satiation). This unfulfilled motivation results in continued attempts to forage which depending on the environment may be expressed as oral stereotypies (Lawrence and Terlouw, 1993). Hemsworth et al. (2015) dump-fed group-housed sows in four morning feeds each separated by an hour. This approach was intended to reduce food competition, the idea being that dominant sows take much of the feed from the first drop, and subordinate sows are able to eat in subsequent feed drops.

In the United Kingdom, the law requires that sows are fed at least once a day, but elsewhere, feeding sows every 2 or even 3 days has been tried. Douglas et al. (1998) fed sows on a low-fibre (corn-soybean) diet 2 kg daily or 6 kg at an interval of once every third day. With reduced meal frequency, interval-fed sows show lower levels of oral behaviours including sham chewing, licking, feeding and excess drinking; sows were also less active every day. The hormone cholecystokinin which indicates satiation (increased likelihood of a meal ending) was found to be higher post-meal but lower pre-meal in interval-fed compared to daily fed sows. Blood glucose was similar in both groups before feeding but was higher after feeding in interval-fed sows compared to daily fed.

To summarise, more regular meals can lead to more regular stimulation of the positive feedback in feeding motivation which results in redirected oral behaviours, and in sows being more active. On the other hand, more regular meals level out the energy supply over time, resulting in an increase in physiological signs of satiety prior to the next meal, reduced food motivation prior to the next meal, and more stability in blood concentrations of energy substrates such as glucose and NEFA.

7.13 The impact of sow diet and feeding methods on the piglets

7.13.1 Impacts of sow diet on piglet production

Various authors have investigated the effects of sow fibre diets on production parameters including parturition progress, litter size, piglet growth and weaning weight. Effects are often absent or rather small (Vestergaard and Danielsen, 1998; Guillemet et al., 2007b; Darroch et al., 2008; Veum et al., 2009), although in a review of 24 high-fibre feeding trials in the United States, Reese et al. (2008) concluded that high-fibre diets increased litter size in the second reproductive cycle. It is perhaps not surprising that fibre effects on production are difficult to pin down as sow reproduction seems relatively unaffected by nutritional interventions in pregnancy; even doubling the quantity of feed provided during early (Quesnel et al., 2010) or late (Pond et al., 1981) gestation has little effect on embryo survival and subsequent litter size or birth weight.

A further complicating factor is that many of these production trials often do not succeed in equalising energy intake or weight gain across different feeding treatments (see Section 7.6 and D'Eath et al., 2009). For example, these feeding trials report differences in energy intake during pregnancy (Mroz et al., 1986; Vestergaard and Danielsen, 1998; Veum et al., 2009), differences in sow body weight (McGlone and Fullwood, 2001; Darroch et al., 2008), body weight and backfat thickness (Mroz et al., 1986; Matte et al., 1994; van der Peet-Schwering et al., 2003) and in backfat and leptin levels (Quesnel et al., 2009) at the end of pregnancy.

It is also evident in a number of these studies that compensation can occur at different stages of the reproductive cycle. Sows that grow less, or are less fat at the end of pregnancy, often eat more during lactation (Matte et al., 1994; Vestergaard and Danielsen, 1998; Guillemet et al., 2007b; Quesnel et al., 2009). These sows might have smaller piglets, but then eat more, and produce more milk during lactation meaning that their piglets' weights have caught up by the time they reach weaning age (Matte et al., 1994).

Finally, it is possible that a very short period of fibre feeding might have effects on production. High-fibre diets in the last week of pregnancy resulted in increased colostrum intake of low birth weight piglets, and decreased preweaning mortality (Loisel et al., 2013), presumably because lactation feed intake was stimulated. There may also be an effect on ease of farrowing: sows fed higher fibre diets at the end of gestation and in the few days prior to farrowing had less constipation and piglets grew faster in the first 5 days of life (Oliviero et al., 2009). Also, pre-insemination effects of fibre feeding have been found; high fibre during the oestrus cycle prior to insemination can affect embryo survival and the number of piglets affected by intrauterine growth retardation in early pregnancy (Ferguson et al., 2006, 2007) leading to increased numbers born alive (Ferguson et al., 2004).

7.13.2 Potential impacts of sow diet on piglet welfare

Stressful events experienced by the sow during pregnancy can affect future outcomes for their offspring (pre-natal stress). Various experiments have imposed stressful challenges on pregnant sows such as social mixing, restraint, cold or heat or by inducing physiological stress through injection of synthetic glucocorticoids or adrenocorticotropic hormone (Rutherford et al., 2012; Otten et al., 2015). These challenges can result in a variety of piglet outcomes including decreased piglet weight gain post-weaning, disturbed social behaviour, increased stress reactivity and responsiveness to pain.

There has been relatively little work on the effects of sow nutrition in pregnancy on outcomes for piglet welfare. Recently, Bernardino et al. (2016) reported that piglets of high-fibre-fed sows had lower skin lesions just before weaning than piglets of low-fibre-fed sows which could indicate reduced aggression between littermates, although this may be an artefact because these piglets were also in smaller litters. In various rodent species, challenges such as restricted feeding during pregnancy can alter a range of physiological systems in the offspring, particular those which regulate feeding and metabolism (Sferruzzi-Perri and Camm, 2016). In sheep, 50% food restriction during pregnancy increased physiological response (hypothalamic pituitary adrenal axis) to stress in their 2-month old lamb offspring (Chadio et al., 2007). Although the quantitative nutritional challenges in rodent and sheep models are different to feeding iso-energetic diets differing in fibre content, it is possible that piglet welfare could be affected by fibre feeding. The more stable levels of insulin and glucose (De Leeuw et al., 2004, 2005a) and the presence of higher levels of SCFA in the sow's blood (Jensen et al., 2015) could influence energy supply to the piglet foetuses. Also, the overall pre-natal piglet experience is affected by the combination of diet, feeding and housing system (including space, social groups and provision of substrates), which combine to influence sow stress during pregnancy.

7.14 Environmental impacts of fibre diets for sows

7.14.1 Manure handling and nitrogenous emissions

Inclusion of insoluble fibre sources that are poorly fermented are expected to increase faecal weight and bulk due to the passage of undigested fibres and their water holding capacity (Lee and Close, 1987; Bach Knudsen and Hansen, 1991). This results in an increase in manure volume. Increased faecal particle size resulting from some sources of insoluble fibre (Lee and Close, 1987) can lead to practical problems of manure handling in liquid-based slurry systems. Fermentable fibre increases faecal output to a lesser extent due to an increase in microbial biomass (Bach Knudsen and Hansen, 1991), so is preferable in this regard.

Fermentable fibre in the diet results in more nitrogenous waste being excreted as bacterial protein in faeces rather than as urea in urine. As urea rapidly breaks down to release CO_2 and ammonia, fermentable fibre in the diet can mean considerably reduced or delayed ammonia emissions from slurry (Bindelle et al., 2008). The resulting increased N content of pig manure can increase its value as a fertiliser in mixed livestock-cropping systems, particularly for farmers in tropical regions where organic matter and N content of the soil is often low and limiting.

7.14.2 Greenhouse gas emissions

Philippe et al. (2009) measured greenhouse gas emissions from straw-bedded sows on conventional cereals-based diets and on ad libitum diets with 42% sugar beet pulp. Although ammonia (NH_3), methane (CH_4) and carbon dioxide (CO_2) emissions were all higher for the fibre-fed sows, emissions of the potent greenhouse gas nitrous oxide (N_2O) were considerably lower, meaning that the overall CO_2 equivalent emissions were reduced by 44%.

Depending on the formulation, many high-fibre diets have reduced energy density, meaning that a greater total weight of feed is required per sow, unless high-energy density ingredients are added. Depending on the source of ingredients and location of feed processing, the requirement for a greater quantity of a less energy dense single processed feed could result in an increased carbon footprint of pig feed production. Production of feed typically constitutes 78% of the carbon footprint of pig production (Fry and Kingston, 2009).

On the other hand, an increase in the use of locally grown (or byproduct) fibre sources that sows can ferment in their hind-guts and obtain energy from might reduce the environmental impact of pig production. This is particularly true if local fibre sources displace grains or imported soya that could have been used directly in human food (Weightman et al., 2011; Reckmann et al., 2016). Indeed, Sonesson et al. (2016) found that locally sourced sugar beet pulp had a relatively low environmental impact.

7.15 Future trends

Current genetic selection for rapid growth and (in particular) for large litter size, resulting in an increased need for the use of 'nurse' sows, are putting real pressure on sows (Baxter et al., 2013; Rutherford et al., 2013; Baxter et al., Chapter 2: Sow welfare in the farrowing crate and alternatives). Fertility and longevity are issues of concern, with young sows predominant in the herd. For example, a recent study of 87 farms in The Netherlands between 2000 and 2008, 45% of farrowing records were for 1st and 2nd parity sows (Hoving et al., 2011a). There is a challenge in identifying how best to feed the modern sow at all stages of the production cycle to ensure good production, welfare and longevity. This may include a reduction in the extent of pregnancy feed restriction. For example, increased rations during the first trimester for sows in their second parity can increase litter size (Hoving et al., 2011b).

The requirement in the EU to provide sows with dietary fibre and foraging substrates is implemented in highly variable ways (Bracke, Chapter 6: Chains as proper enrichment for intensively-farmed pigs?). The latest research reviewed above suggests fermentable, soluble fibres or resistant starch have the greatest effect on physiology and behaviour, and the challenge now is to increase the use of these fibre types in farm diets in a way that is practical and affordable. For example, these fibres may not need to be fed in the trough. Sows eat their bedding straw and there may be other more appropriate materials containing a greater proportion of soluble fibres that could serve the dual purpose of bedding and food.

Both fibre and foraging material can reduce the extent to which oral behaviours are directed towards inappropriate targets such as drinkers, empty feeders, pen bars, etc. but the welfare consequences of this change have been debated. The relative extent to which increasing dietary energy, dietary fibre or access to foraging substrates affect the welfare of the dry sow is not well understood. The behavioural need to explore for its own sake, once feeding needs are met, may be much less in adult sows than it is in young pigs (Lawrence et al., 1988; Terlouw et al., 1991).

Finally, there has been relatively little work to understand the causes and effects of gastric ulcers for sows, how this welfare problem interacts with the issue of satiety, and how diet, feeding system and bedding provision interact. Also, the possibility of pre-natal programming effects of the sow's experience on her piglets requires further attention in different industry-relevant situations, again considering the possible interaction of diet, housing and feeding system.

7.16 Overall summary/conclusions

Sows have their energy intake rationed to avoid obesity, which improves longevity, reduces lameness and results in efficient production. Sows' behaviour suggest they are hungry when fed on these rationed diets; they show increased activity and foraging-related oral behaviour, and motivation to access additional food if it is available. In some systems, these oral behaviours have no natural outlet, leading to redirected and sometimes 'abnormal' expressions of oral behaviour such as bar--biting, sham-chewing and over-drinking.

Confinement in stalls in particular frustrates behavioural expression, and group housing is a better alternative in this respect, but brings different challenges, most notably achieving equal ration feeding to all sows in a group without provoking aggression (Verdon and Rault, Chapter 8: Aggression in group housed sows and fattening pigs). The industry trend worldwide is to move away from confinement systems to group housing. This is happening in different countries over differing timescales, as a result of legal and/or voluntary changes.

Providing fibre in dry sow diets, while still restricting energy intake, can contribute to a more normal expression of eating and foraging behaviour, in the sense that redirected oral behaviours are reduced. Fibre provision is required in the EU. Fibre, particularly soluble fermentable fibre or resistant starch, has beneficial effects on short-term satiety due to its physical properties in the gut, and because hindgut fermentation of fibre into SCFAs results in prolonged energy supply. Various behavioural and physiological measures reflect this; fibre-fed sows spend longer eating, have reduced activity post-meal, and show more stable blood glucose and insulin concentrations. However, fibre does not completely satisfy energy-restricted dry sows: if additional food is offered, high-fibre-fed sows will 'work' as hard (or almost as hard) as low-fibre-fed sows in operant tasks to access it.

Dry sows, like other pigs, are motivated to perform natural foraging behaviours such as rooting and chewing at suitable substrates. These behaviours are increased in dry sows as a result of their food rationing. In the EU at least, all pigs are required to have access to suitable manipulable materials as an outlet for these behaviours (Bracke, this volume).

Industry practices vary in different countries, but in most cases there is insufficient provision of the types and amounts of dietary fibre that have been shown by research to reduce sow hunger. Similarly, sows are not always provided with sufficient quantities of suitable types of foraging material. For example in the United Kingdom, industry diets contain some additional insoluble fibre, although foraging opportunities exist due to the use of straw bedding or outdoor pastures. An increase in the use of fibre in feed ingredients may affect waste-handling on farm, although this is less of a problem if soluble fibre is used. Depending on the type, source and what it displaces, fibre can have wider positive or negative environmental impacts; if fibrous food is imported and processed then a greater carbon footprint could result from transporting a greater weight of feed. On the other hand, a lower carbon footprint results if locally sourced byproduct or fodder crops are used, and energy from fermentation of fibre displaces energy from imported feed ingredients.

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Abbreviations

ADF acid-detergent fibre
ADL acid-detergent lignin
AI artificial insemination
DE digestible energy
GE gross energy
ME metabolisable energy
NDF neutral-detergent fibre
NE net energy
NEFAs non-esterified fatty acids
NSPs non-starch polysaccharides
SCFAs short-chain fatty acids

References

Agricultural Research Council, 1967. The Nutrient Requirement of Farm Livestock, No. 3 Pigs. Agricultural Research Council, London.

Amdi, C., Giblin, L., Ryan, T., Stickland, N.C., Lawlor, P.G., 2014. Maternal backfat depth in gestating sows has a greater influence on offspring growth and carcass lean yield than maternal feed allocation during gestation. Animal. 8, 236−244.

Bach Knudsen, K.E., 1997. Carbohydrate and lignin contents of plant materials used in animal feeding. Anim. Feed Sci. Technol. 67, 319−338.

Bach Knudsen, K.E., 2001. The nutritional significance of "dietary fibre" analysis. Anim. Feed Sci. Technol. 90, 3−20.

Bach Knudsen, K.E., Hansen, I., 1991. Gastrointestinal implications in pigs of wheat and oat fractions. Br. J. Nutr. 65, 217−232.

Barbano, M.F., Cador, M., 2006. Differential regulation of the consummatory, motivational and anticipatory aspects of feeding behavior by dopaminergic and opioidergic drugs. Neuropsychopharmacology. 31, 1371−1381.

Barnett, J.L., Hemsworth, P.H., Cronin, G.M., Jongman, E.C., Hutson, G.D., 2001. A review of the welfare issues for sows and piglets in relation to housing. Aust. J. Agric. Res. 52, 1–28.

Baxter, E.M., Rutherford, K.M.D., D'Eath, R.B., Arnott, G., Turner, S.P., Sandoe, P., Moustsen, V., Thorup, F., Edwards, S.A., Lawrence, A.B., 2013. The welfare implications of large litter size in the domestic pig II: management factors. Anim. Welfare. 22, 219–238.

Baxter, E.M., Andersen, I.L., Edwards, S.A., 2017. Sow welfare in the farrowing crate and alternatives. In: Špinka, M. (Ed.), Advances in Pig Welfare. Woodhead Publishing, Duxford, UK.

Benelam, B., 2009. Satiation, satiety and their effects on eating behaviour. Nutr. Bull. 34, 126–173.

Bergeron, R., Bolduc, J., Ramonet, Y., Meunier-Salaun, M.C., Robert, S., 2000. Feeding motivation and stereotypies in pregnant sows fed increasing levels of fibre and/or food. Appl. Anim. Behav. Sci. 70, 27–40.

Bernardino, T., Tatemoto, P., Morrone, B., Mazza Rodrigues, P.H., Zanella, A.J., 2016. Piglets born from sows fed high fibre diets during pregnancy are less aggressive prior to weaning. PLoS One. 11, e0167363.

Bindelle, J., Buldgen, A., Leterme, P., 2008. Nutritional and environmental consequences of dietary fibre in pig nutrition: a review. Biotechnol. Agron. Soc. Environ. (BASE). 12, 69–80.

Blackwood, A.D., Salter, J., Dettmar, P.W., Chaplin, M.F., 2000. Dietary fibre, physicochemical properties and their relationship to health. J. R. Soc. Promotion Health. 120, 242–247.

Boswell, T., Dunn, I.C., 2015. Regulation of the avian central melanocortin system and the role of leptin. Gen. Comp. Endocrinol. 221, 278–283.

Bracke, M., 2017. Chains as proper enrichment for intensively-farmed pigs? In: Špinka, M. (Ed.), Advances in Pig Welfare. Woodhead Publishing, Duxford, UK.

Brouns, F., Edwards, S.A., English, P.R., 1994a. Effect of dietary fiber and feeding system on activity and oral behavior of group-housed gilts. Appl. Anim. Behav. Sci. 39, 215–223.

Brouns, F., Edwards, S.A., English, P.R., 1994b. Metabolic effects of fibrous ingredients in pig diets. Anim. Prod. 58, 467.

Brouns, F., Edwards, S.A., English, P.R., 1995. Influence of fibrous feed ingredients on voluntary intake of dry sows. Anim. Feed Sci. Technol. 54, 301–313.

Brownlee, I.A., 2011. The physiological roles of dietary fibre. Food Hydrocolloid. 25, 238–250.

Canibe, N., Højberg, O., Højsgaard, S., Jensen, B.B., 2005. Feed physical form and formic acid addition to the feed affect the gastrointestinal ecology and growth performance of growing pigs. J. Anim. Sci. 83, 1287–1302.

Chadio, S.E., Kotsampasi, B., Papadomichelakis, G., Deligeorgis, S., Kalogiannis, D., Menegatos, I., Zervas, G, 2007. Impact of maternal undernutrition on the hypothalamic-pituitary-adrenal axis responsiveness in sheep at different ages postnatal. J. Endocrinol. 192, 495–503.

CIWF, 2009. Welfare of pigs in the European Union—the urgent need for reform of existing legislation and effective enforcement. Godalming, Surrey, UK, Compassion in World Farming.

CIWF, 2013. Food business. Indoor housing systems for dry sows—practical options. Godalming, Surrey, Compassion in World Farming Food Business.

Cummings, J.H., Stephen, A.M., 2007. Carbohydrate terminology and classification. Eur. J. Clin. Nutr. 61, S5–S18.

Dailey, J.W., McGlone, J.J., 1997. Oral/nasal/facial and other behaviors of sows kept individually outdoors on pasture, soil or indoors in gestation crates. Appl. Anim. Behav. Sci. 52, 25–43.

Danielsen, V., Vestergaard, E.M., 2001. Dietary fibre for pregnant sows: effect on performance and behaviour. Anim. Feed Sci. Technol. 90, 71–80.

Darroch, C.S., Dove, C.R., Maxwell, C.V., Johnson, Z.B., Southern, L.L., 2008. A regional evaluation of the effect of fiber type in gestation diets on sow reproductive performance. J. Anim. Sci. 86, 1573–1578.

Dawkins, M.S., 2006. A user's guide to animal welfare science. Trends Ecol. Evol. 21, 77–82.

Day, J.E.L., Kyriazakis, I., Lawrence, A.B., 1996a. The use of a second-order schedule to assess the effect of food bulk on the feeding motivation of growing pigs. Anim. Sci. 63, 447–455.

Day, J.E.L., Kyriazakis, I., Lawrence, A.B., 1996b. The use of a second-order schedule to measure feeding motivation in the pig. Appl. Anim. Behav. Sci. 50, 15–31.

Day, J.E.L., Kyrizakis, I., Lawrence, A.B., 1996c. An investigation into the causation of chewing behaviour in growing pigs: the role of exploration and feeding motivation. Appl. Anim. Behav. Sci. 48, 47–59.

Day, J.E.L., Kyriazakis, I., Rogers, P.J., 1998. Food choice and intake: towards a unifying framework of learning and feeding motivation. Nutr. Res. Rev. 11, 25–43.

D'Eath, R.B., Tolkamp, B.J., Kyriazakis, I., Lawrence, A.B., 2009. 'Freedom from hunger' and preventing obesity: the animal welfare implications of reducing food quantity or quality. Anim. Behav. 77, 275–288.

De Decker, A., Hanson, A., Walker, P., Salak-Johnson, J., 2014. Space allowance and high fiber diet impact performance and behavior of group-kept gestating sows. J. Anim. Sci. 92, 1666–1674.

de Jonge, F.H., Tilly, S.-L., Baars, A.M., Spruijt, B.M., 2008. On the rewarding nature of appetitive feeding behaviour in pigs (*Sus scrofa*): do domesticated pigs contrafreeload? Appl. Anim. Behav. Sci. 114, 359–372.

De Leeuw, J.A., 2004. Stimulation of Behavioural and Nutritional Satiety in Sows. Wageningen University, The Netherlands.

De Leeuw, J.A., Jongbloed, A.W., Verstegenl, M.W.A., 2004. Dietary fiber stabilizes blood glucose and insulin levels and reduces physical activity in sows (*Sus scrofa*). J. Nutr. 134, 1481–1486.

De Leeuw, J.A., Jongbloed, A.W., Spoolder, H.A.M., Verstegen, M.W.A., 2005a. Effects of hindgut fermentation of non-starch polysaccharides on the stability of blood glucose and insulin levels and physical activity in empty sows. Livest. Prod. Sci. 96, 165–174.

De Leeuw, J.A., Zonderland, J.J., Altena, H., Spoolder, H.A.M., Jongbloed, A.W., Verstegen, M.W.A., 2005b. Effects of levels and sources of dietary fermentable non-starch polysaccharides on blood glucose stability and behaviour of group-housed pregnant gilts. Appl. Anim. Behav. Sci. 94, 15–29.

de Leeuw, J.A., Bolhuis, J.-E., Bosch, G., Gerrits, W.-J., 2008. Effects of dietary fibre on behaviour and satiety in pigs. Proc. Nutr. Soc. 67, 334–342.

Douglas, M.W., Cunnick, J.E., Pekas, J.C., Zimmerman, D.R., von Borell, E.H., 1998. Impact of feeding regimen on behavioral and physiological indicators for feeding and motivation and satiety, immune function, performance of gestating sows. J. Anim. Sci. 76, 2589–2595.

Douglas, S.L., Szyszka, O., Stoddart, K., Edwards, S.A., Kyriazakis, I., 2014. A meta-analysis to identify animal and management factors influencing gestating sow efficiency. J. Anim. Sci. 92, 5716–5726.
Dourmad, J.Y., Etienne, M., Prunier, A., Noblet, J., 1994. The effect of energy and protein intake of sows on their longevity: a review. Livest. Prod. Sci. 40, 87–97.
Edwards, S.A., 2002. Feeding Organic Pigs—A Handbook of Raw Materials and Recommendations for Feeding Practice. University of Newcastle upon Tyne, Newcastle, UK.
Elsley, F.W.H., Macphers, R.M., Mcdonald, I., 1968. Influence of intake of dietary energy in pregnancy and lactation upon sow productivity. J. Agric. Sci. 71, 215–222.
Elsley, F.W.H., Bannerman, M., Bathurst, E.V.J., Bracewell, A.G., Cunningham, J.M.M., Dodsworth, T.L., Dodds, P.A., Forbes, T.J., Laird, R., 1969. The effect of level of feed intake in pregnancy and in lactation upon the productivity of sows. Anim. Prod. 11, 225–241.
EFSA, 2007. Animal health and welfare aspects of different housing and husbandry systems for adult breeding boars, pregnant, farrowing sows and unweaned piglets (Question No EFSA-Q-2006-028). EFSA J. 572, 1–13.
EUSVC, 1997. The welfare of intensively kept pigs. Report of the Scientific Veterinary Committee of the EU. 1930.
Farmer, C., Meunier-Salaun, M.C., Bergeron, R., Robert, S., 2002. Hormonal response of pregnant gilts fed a high-fiber or a concentrate diet once or twice daily. Can. J. Anim. Sci. 82, 159–164.
Ferguson, E.M., Ashworth, C.J., Hunter, M.G., Penny, P., Slevin, J., Edwards, S.A., 2004. The effect of feeding a high fibre diet from mid lactation until breeding on subsequent litter size of sows. In: Thompson, J.E., Gill, B.P., Varley, M.A. (Eds.), The Appliance of Pig Science. Nottingham University Press, Nottingham, UK, pp. 175–179.
Ferguson, E.M., Slevin, J., Edwards, S.A., Hunter, M.G., Ashworth, C.J., 2006. Effect of alterations in the quantity and composition of the pre-mating diet on embryo survival and foetal growth in the pig. Anim. Reprod. Sci. 96, 89–103.
Ferguson, E.M., Slevin, J., Hunter, M.G., Edwards, S.A., Ashworth, C.J., 2007. Beneficial effects of a high fibre diet on oocyte maturity and embryo survival in gilts. Reproduction. 133, 433–439.
Fraser, D., 1975. Effect of straw on behavior of sows in tether stalls. Anim. Prod. 21, 59–68.
Friedman, M.I., Horn, C.C., Ji, H., 2005. Peripheral signals in the control of feeding behavior. Chem. Sens. 30, I182–I183.
Friendship, R.M., 2004. Gastric ulceration in swine. J. Swine Health Prod. 12, 34–35.
Fry, J., Kingston, T., 2009. Life cycle assessment of pork. A report by environmental resources management for agriculture and horticulture development board meat services AHDB.
Guillemet, R., Comyn, S., Dourmad, J.Y., Meunier-Salaün, M.C., 2007a. Gestating sows prefer concentrate diets to high-fibre diet in two-choice tests. Appl. Anim. Behav. Sci. 108, 251–262.
Guillemet, R., Hamard, A., Quesnel, H., Pere, M.C., Etienne, M., Dourmad, J.Y., Meunier-Salaun, M.C., 2007b. Dietary fibre for gestating sows: effects on parturition progress, behaviour, litter and sow performance. Animal. 1, 872–880.
Hansen, A.V., 2012. Feed intake in reproducing sows. In: Bach Knudsen, K.E., Kjeldsen, N.J., Poulsen, H.D., Jensen, B.B. (Eds.), Nutritional Physiology of Pigs. SEGES Videncenter for Svineproducktion, Foulum, Denmark.
Hazzledine, M., 2014. What might we be feeding in 2020? Development in pig feed ingredients. In: BPEX Innovation Conference, Stoneleigh Park, Warwickshire, UK.
Hemsworth, P., Morrison, R., Tilbrook, A., Butler, K., Rice, M., Moeller, S., 2015. Effects of floor space on the welfare of group housed sows 1C-105. Report prepared for the co-operative research centre for high integrity Australian Pork, Pork CRC, Australia.

Henry, Y., 1970. Effets nutritionnels de l'incorporation de cellulose purifiée dans le regime du porc en croissance-finition. III. Incidence sur le developpement des ulceres gastro-oesophagiens. Annal. Zootech. 19, 117–137.

Herskin, M.S., Jensen, H.E., Jespersen, A., Forkman, B., Jensen, M.B., Canibe, N., Pedersen, L.J., 2016. Impact of the amount of straw provided to pigs kept in intensive production conditions on the occurrence and severity of gastric ulceration at slaughter. Res. Vet. Sci. 104, 200–206.

Holt, J.P., Johnston, L.J., Baidoo, S.K., Shurson, G.C., 2006. Effects of a high-fiber diet and frequent feeding on behavior, reproductive performance, and nutrient digestibility in gestating sows. J. Anim. Sci. 84, 946–955.

Houdijk, J.G.M., 1998. Effects of Non-Digestible Oligosaccharides in Young Pig Diets. PhD Thesis Wageningen Agricultural University, Ponsen en van Looijen.

Hoving, L.L., Soede, N.M., Graat, E.A.M., Feitsma, H., Kemp, B., 2011a. Reproductive performance of second parity sows: relations with subsequent reproduction. Livest. Sci. 140, 124–130.

Hoving, L.L., Soede, N.M., Peet-Schwering, C.M.C., Graat, E.A.M., Feitsma, H., Kemp, B., 2011b. An increased feed intake during early pregnancy improves sow body weight recovery and increases litter size in young sows. J. Anim. Sci. 89, 3542–3550.

Howarth, N.C., Saltzman, E., Roberts, S.B., 2001. Dietary fiber and weight regulation. Nutr. Rev. 59, 129–139.

Hughes, B.O., Duncan, I.J.H., 1988. The notion of ethological 'need', models of motivation and animal welfare. Anim. Behav. 36, 1696–1707.

Hutson, G.D., 1991. A note on hunger in the pig – sows on restricted rations will sustain an energy deficit to gain additional food. Anim. Prod. 52, 233–235.

Jaworski, N.W., Lærke, H.N., Bach Knudsen, K.E., Stein, H.H., 2015. Carbohydrate composition and in vitro digestibility of dry matter and nonstarch polysaccharides in corn, sorghum, and wheat and coproducts from these grains1. J. Anim. Sci. 93, 1103–1113.

Jensen, M.B., Pedersen, L.J., 2007. The value assigned to six different rooting materials by growing pigs. Appl. Anim. Behav. Sci. 108, 31–44.

Jensen, M.B., Kyriazakis, I., Lawrence, A.B., 1993. The activity and straw directed behavior of pigs offered foods with different crude protein content. Appl. Anim. Behav. Sci. 37, 211–221.

Jensen, M.B., Pedersen, L.J., Theil, P.K., Yde, C.C., Bach Knudsen, K.E., 2012. Feeding motivation and plasma metabolites in pregnant sows fed diets rich in dietary fiber either once or twice daily. J. Anim. Sci. 90, 1910–1919.

Jensen, M.B., Pedersen, L.J., Theil, P.K., Bach Knudsen, K.E., 2015. Hunger in pregnant sows: Effects of a fibrous diet and free access to straw. Appl. Anim. Behav. Sci. 171, 81–87.

Jensen, P., Toates, F.M., 1993. Who needs 'behavioural needs'? Motivational aspects of the needs of animals. Appl. Anim. Behav. Sci. 37, 161–181.

Jha, R., Berrocoso, J.D., 2015. Review: dietary fiber utilization and its effects on physiological functions and gut health of swine. Animal. 9, 1441–1452.

Jørgensen, B., Sørensen, M.T., 1998. Different rearing intensities of gilts: II. Effects on subsequent leg weakness and longevity. Livest. Prod. Sci. 54, 167–171.

Jørgensen, H., Theil, P.K., Bach Knudsen, K.E., 2010. Satiating properties of diets rich in dietary fibre fed to sows as evaluated by physico-chemical properties, gastric emptying rate and physical activity. Livest. Sci. 134, 37–40.

Jørgensen, L., Jensen, B.B., 2004. Melfoder og pelleteret foder til søer [Meal feeding or pellet feeding for sows]. Meddelelse NR. 668. Copenhagen, SEGES Videncenter for Svineproduktion (Danish Pig Research Centre).

Kirkden, R.D., Pajor, E., 2006. Using preference, motivation and aversion tests to ask scientific questions about animals' feelings. Appl. Anim. Behav. Sci. 100, 29–47.

Kirkwood, R.N., Aherne, F.X., 1985. Energy intake, body composition and reproductive performance of the gilt. J. Anim. Sci. 60, 1518–1529.

Lawrence, A.B., Illius, A.W., 1989. Methodology for measuring hunger and food-needs using operant- conditioning in the pig. Appl. Anim. Behav. Sci. 24, 273–285.

Lawrence, A.B., Terlouw, E.M.C., 1993. A review of the behavioural factors involved in the development and continued performance of stereotypic behaviors in pigs. J. Anim. Sci. 71, 2815–2825.

Lawrence, A.B., Appleby, M.C., Macleod, H.A., 1988. Measuring hunger in the pig using operant-conditioning—the effect of food restriction. Anim. Prod. 47, 131–137.

Lawrence, A.B., Appleby, M.C., Illius, A.W., Macleod, H.A., 1989. Measuring hunger in the pig using operant-conditioning—the effect of dietary bulk. Anim. Prod. 48, 213–220.

Lee, P.A., Close, W.H., 1987. Bulky feeds for pigs: a consideration of some non-nutritional aspects. Livest. Prod. Sci. 16, 395–405.

Le Goff, G., Noblet, J., 2001. Comparative total tract digestibility of dietary energy and nutrients in growing pigs and adult sows. J. Anim. Sci. 79, 2418–2427.

Li, Y.Z., Gonyou, H.W., 2013. Comparison of management options for sows kept in pens with electronic feeding stations. Can. J. Anim. Sci. 93, 445–452.

Lodge, G.A., 1969. The effects of pattern of feed distribution during the reproductive cycle on the performance of sows. Anim. Prod. 11, 133–143.

Lodge, G.A., Mcdonald, I., Macpherson, R.M., 1961. Weight changes in sows during pregnancy and lactation. Anim. Sci. 3, 269–275.

Loisel, F., Farmer, C., Ramaekers, P., Quesnel, H., 2013. Effects of high fiber intake during late pregnancy on sow physiology, colostrum production, and piglet performance. J. Anim. Sci. 91, 5269–5279.

Marchant, J.N., Broom, D.M., 1996. Effects of dry sow housing conditions on muscle weight and bone strength. Anim. Sci. 62, 105–113.

Marchant, J.N., Rudd, A.R., Broom, D.M., 1997. The effects of housing on heart rate of gestating sows during specific behaviours. Appl. Anim. Behav. Sci. 55, 67–78.

Marchant-Forde, J.N., 2009. Welfare of dry sows. In: Marchant-Forde, J.N. (Ed.), The Welfare of Pigs. Springer, Berlin, Germany, pp. 95–139.

Matte, J.J., Robert, S., Girard, C.L., Farmer, C., Martineau, G.P., 1994. Effect of bulky diets based on wheat bran or oat hulls on reproductive-performance of sows during their first 2 parities. J. Anim. Sci. 72, 1754–1760.

Maxson, D.W., Stanley, G.R., Perry, T.W., Pickett, R.A., Curtin, T.M., 1968. Influence of various ratios of raw and gelatinized corn, oats, oat components and sand on the incidence of esophagogastric lesions in swine. J. Anim. Sci. 27, 1006–1010.

McGlone, J., 2013. Sow stalls—a brief history. Pig progress. Available from: <http://www.pigprogress.net/Home/General/2013-12/Sow-stalls--a-brief-history-1388603W/>.

McGlone, J.J., Fullwood, S.D., 2001. Behavior, reproduction, and immunity of crated pregnant gilts: effects of high dietary fiber and rearing environment. J. Anim. Sci. 79, 1466–1474.

McGlone, J.J., Salak-Johnson, J., 2009. Changing from sow gestation crates to pens: problem or opportunity. <http://www.thepigsite.com/articles/2672/changing-from-sow-gestation-crates-to-pens-problem-or-opportunity/>.

Mela, D.J., Rogers, P.J., 1998. Food, Eating and Obesity. The Psychobiological Basis of Appetite and Weight Control. Chapman and Hall, London.

Mertens, D.R., 2003. Challenges in measuring insoluble dietary fiber. J. Anim. Sci. 81, 3233–3249.

Meunier-Salaün, M.C., Bolhuis, J.E., 2015. High-fibre feeding in gestation. In: Farmer, C. (Ed.), The Gestating and Lactating Sow. Wageningen Academic Publishers, Wageningen, NL, pp. 95–116.

Moustsen, V.A., Lahrmann, H.P., D'Eath, R.B., 2011. Relationship between size and weight of modern hyper-prolific crossbred sows. Livest. Sci. 141, 272–275.

Mroz, Z., Partridge, I.G., Mitchell, G., Keal, H.D., 1986. The effect of oat hulls, added to the basal ration for pregnant sows, on reproductive-performance, apparent digestibility, rate of passage and plasma parameters. J. Sci. Food Agric. 37, 239–247.

Nielsen, E.K., Ingvartsen, K.L., 2000. Effects of cereal disintegration method, feeding method and straw as bedding on stomach characteristics including ulcers and performance in growing pigs. Acta Agric. Scand. Sect. A ΓÇö Anim. Sci. 50, 30–38.

Noblet, J., Le Goff, G., 2001. Effect of dietary fibre on the energy value of feeds for pigs. Anim. Feed Sci. Technol. 90, 35–52.

Oliviero, C., Kokkonen, T., Heinonen, M., Sankari, S., Peltoniemi, O., 2009. Feeding sows with high fibre diet around farrowing and early lactation: impact on intestinal activity, energy balance related parameters and litter performance. Res. Vet. Sci. 86, 314–319.

Olsson, A.C., Andersson, M., Botermans, J., Rantzer, D., Svendsen, J., 2011. Animal interaction and response to electronic sow feeding (ESF) in 3 different herds and effects of function settings to increase capacity. Livest. Sci. 137, 268–272.

Otten, W., Kanitz, E., Tuchscherer, M., 2015. The impact of pre-natal stress on offspring development in pigs. J. Agric. Sci. 153, 907–919.

Philippe, F.X., Canart, B., Laitat, M., Wavreille, J., Vandenheede, M., Bartiaux-Thill, N., Nicks, B., Cabaraux, J.F., 2009. Gaseous emissions from group-housed gestating sows kept on deep litter and offered an ad libitum high-fibre diet. Agric. Ecosyst. Environ. 132, 66–73.

Pond, W.G., Yen, J.T., Maurer, R.R., Christenson, R.K., 1981. Effect of doubling daily energy intake during the last two weeks of pregnancy on pig birth weight, survival and weaning weight. J. Anim. Sci. 52, 535–541.

Prunier, A., Heinonen, M., Quesnel, H., 2010. High physiological demands in intensively raised pigs: impact on health and welfare. Animal. 4, 886–898.

Quesnel, H., Meunier-Salaün, M.C., Hamard, A., Guillemet, R., Etienne, M., Farmer, C., Dourmad, J.Y., Père, M.C., 2009. Dietary fiber for pregnant sows: influence on sow physiology and performance during lactation. J. Anim. Sci. 87, 532–543.

Quesnel, H., Boulot, S., Serriere, S., Venturi, E., Martinat-Bott, F., 2010. Post-insemination level of feeding does not influence embryonic survival and growth in highly prolific gilts. Anim. Reprod. Sci. 120, 120–124.

Ramonet, Y., Meunier-Salaun, M.C., Dourmad, J.Y., 1999. High-fiber diets in pregnant sows: digestive utilization and effects on the behavior of the animals. J. Anim. Sci. 77, 591–599.

Ramonet, Y., Bolduc, J., Bergeron, R., Robert, S., Meunier-Salaun, M.C., 2000a. Feeding motivation in pregnant sows: effects of fibrous diets in an operant conditioning procedure. Appl. Anim. Behav. Sci. 66, 21–29.

Ramonet, Y., van Milgen, J., Dourmad, J.Y., Dubois, S., Meunier-Salaun, M.C., Noblet, J., 2000b. The effect of dietary fibre on energy utilisation and partitioning of heat production over pregnancy in sows. Br. J. Nutr. 84, 85–94.

Reckmann, K., Traulsen, I., Krieter, J., 2013. Life cycle assessment of pork production: a data inventory for the case of Germany. Livest. Sci. 157, 586–596.

Reckmann, K., Blank, R., Traulsen, I., Krieter, J., 2016. Comparative life cycle assessment (LCA) of pork using different protein sources in pig feed. Arch. Anim. Breed. 59, 27–36.

Reese, D., Prosch, A., Travnicek, D.A., Eskridge, K.M., 2008. Dietary fiber in sow gestation diets—an updated review.

Reese, D.E., DeRouchey, J.M., van Heugten, E., Johnston, L., Whitney, M.H., Dahlke, G., 2010. National Swine Nutrition Guide—Example Diets for Swine. University of Nebraska, U.S. Pork Center of Excellence.

Rérat, A., Fiszlewicz, M., Giusi, A., Vaugelade, P., 1987. Influence of meal frequency on postprandial variations in the production and absorption of volatile fatty acids in the digestive tract of conscious pigs. J. Anim. Sci. 64, 448−456.

Rijnen, M.M.J.A., Verstegen, M.W.A., Heetkamp, M.J.W., Haaksma, J., Schrama, J.W., 2003. Effects of dietary fermentable carbohydrates on behavior and heat production in group-housed sows. J. Anim. Sci. 81, 182−190.

Robert, S., Matte, J.J., Farmer, C., Girard, C.L., Martineau, G.P., 1993. High-fiber diets for sows—effects on stereotypies and adjunctive drinking. Appl. Anim. Behav. Sci. 37, 297−309.

Robert, S., Rushen, J., Farmer, C., 1997. Both energy content and bulk of food affect stereotypic behaviour, heart rate and feeding motivation of female pigs. Appl. Anim. Behav. Sci. 54, 161−171.

Robert, S., Bergeron, R., Farmer, C., Meunier-Salaun, M.C., 2002. Does the number of daily meals affect feeding motivation and behaviour of gilts fed high-fibre diets? Appl. Anim. Behav. Sci. 76, 105−117.

Ru, Y.J., Bao, Y.M., 2004. Feeding dry sows ad libitum with high fibre diets. Asian-Austral. J. Anim. Sci. 17, 283−300.

Rushen, J., 1985. Stereotypies, aggression and the feeding schedules of tethered sows. Appl. Anim. Behav. Sci. 14, 137−147.

Rushen, J., Robert, S., Farmer, C., 1999. Effects of an oat-based high-fibre diet an insulin, glucose, cortisol and free fatty acid concentrations in gilts. Anim. Sci. 69, 395−401.

Rutherford, K.M.D., Donald, R.D., Arnott, G., Rooke, J.A., Dixon, L., Mehers, J.J.M., Turnbull, J., Lawrence, A.B., 2012. Farm animal welfare: assessing risks attributable to the prenatal environment. Anim. Welfare. 21 (3), 419−429.

Rutherford, K.M.D., Baxter, E., D'Eath, R., Turner, S., Arnott, G., Roehe, R., Ask, B., Sandoe, P., Moustsen, V., Thorup, F., Edwards, S., Berg, P., Lawrence, A., 2013. The welfare implications of large litter size in the domestic pig I: biological factors. Anim. Welfare. 22, 199−218.

Sapkota, A., Marchant-Forde, J.N., Richert, B.T., Lay, D.C., 2016. Including dietary fiber and resistant starch to increase satiety and reduce aggression in gestating sows. J. Anim. Sci. 94 (5), 2117−2127.

Savory, C.J., Lariviere, J.M., 2000. Effects of qualitative and quantitative food restriction treatments on feeding motivational state and general activity level of growing broiler breeders. Appl. Anim. Behav. Sci. 69, 135−147.

Schneeman, B.O., Gallaher, D., 1985. Effects of dietary fiber on digestive enzyme activity and bile acids in the small intestine. Exp. Biol. Med. 180, 409−414.

Serena, A., Jorgensen, H., Knudsen, K., 2008. Digestion of carbohydrates and utilization of energy in sows fed diets with contrasting levels and physicochemical properties of dietary fiber. J. Anim. Sci. 86, 2208−2216.

Serena, A., Jorgensen, H., Knudsen, K., 2009. Absorption of carbohydrate-derived nutrients in sows as influenced by types and contents of dietary fiber. J. Anim. Sci. 87, 136−147.

Sferruzzi-Perri, A.N., Camm, E.J., 2016. The programming power of the placenta. Front. Physiol. 7, 33.

Slavin, J., Green, H., 2007. Dietary fibre and satiety. Nutr. Bull. 32, 32−42.

Soede, N.M., Hoving, L.L., van Leeuwen, J.J.J., Kemp, B., 2013. The second litter syndrome in sows; causes, consequences and possibilities of prevention. In: Proceedings of the 9th International Conference on Pig Reproduction, Olsztyn, Poland. 9. 6. 2013, pp. 28–34.

Sonesson, U.G., Lorentzon, K., Andersson, A., Barr, U.K., Bertilsson, J., Borch, E., Brunius, C., Emanuelsson, M., Göransson, L., Gunnarsson, S., Hamberg, L., Hessle, A., Kumm, K.I, Lundh, Å., Nielsen, T., Åstergren, K., Salomon, E., Sindhöj, E., Stenberg, B., Stenberg, M., Sundberg, M., Wall, H., 2016. Paths to a sustainable food sector: integrated design and LCA of future food supply chains: the case of pork production in Sweden. Int. J. Life Cycle Assess. 21, 664–676.

Souza da Silva, C., 2013. Fermentation in the Gut to Prolong Satiety. Exploring Mechanisms by Which Dietary Fibres Affect Satiety in Pigs. PhD Thesis. Wageningen University, Netherlands.

Souza da Silva, C., van den Borne, J.J.G.C., Gerrits, W.J.J., Kemp, B., Bolhuis, J.E., 2012. Effects of dietary fibers with different physicochemical properties on feeding motivation in adult female pigs. Physiol. Behav. 107, 218–230.

Souza da Silva, C., Bolhuis, J.E., Gerrits, W.J.J., Kemp, B., van den Borne, J.J.G.C., 2013. Effects of dietary fibers with different fermentation characteristics on feeding motivation in adult female pigs. Physiol. Behav. 110–111, 148–157.

Spoolder, H.A.M., Burbidge, J.A., Edwards, S.A., Simmins, P.H., Lawrence, A.B., 1995. Provision of straw as a foraging substrate reduces the development of excessive chain and bar manipulation in food restricted sows. Appl. Anim. Behav. Sci. 43, 249–262.

Spruijt, B.M., van den Bos, R., Pijlman, F.T.A., 2001. A concept of welfare based on reward evaluating mechanisms in the brain: anticipatory behaviour as an indicator for the state of reward systems. Appl. Anim. Behav. Sci. 72, 145–171.

Stewart, C.L., O'Connell, N.E., Boyle, L., 2008. Influence of access to straw provided in racks on the welfare of sows in large dynamic groups. Appl. Anim. Behav. Sci. 112, 235–247.

Stewart, C.L., Boyle, L.A., O'Connell, N.E., 2011. The effect of increasing dietary fibre and the provision of straw racks on the welfare of sows housed in small static groups. Anim. Welfare. 20 (4), 633–640.

Studnitz, M., Jensen, K.H., Jorgensen, E., Jensen, K.K., 2003. The effect of nose ringing on exploratory behaviour in gilts. Anim. Welfare. 12, 109–118.

Studnitz, M., Jensen, M.B., Pedersen, L.J., 2007. Why do pigs root and in what will they root? A review on the exploratory behaviour of pigs in relation to environmental enrichment. Appl. Anim. Behav. Sci. 107, 183–197.

Terlouw, E.M.C., Lawrence, A.B., Ilius, A.W., 1991. Influences of feeding level and physical restriction on development of stereotypies in sows. Anim. Behav. 42, 981–991.

Terlouw, E.M.C., Wiersma, A., Lawrence, A.B., Macleod, H.A., 1993. Ingestion of food facilitates the performance of stereotypies in sows. Anim. Behav. 46, 939–950.

The Council of The European Union, 2001. Council Directive 2001/88/EC of 23rd October 2001 amending Directive 91/630/EEC laying down minimum standards for the protection of pigs. Official Journal L 316, 01.12.2001, pp. 1–4.

The Council of The European Union, 2008. Council Directive 2008/120/EC of 18 December 2008 laying down minimum standards for the protection of pigs. The Official Journal L47, pp. 5–13.

Thiel, P., 2015. Transition feeding of sows. In: Farmer, C. (Ed.), The Gestating and Lactating Sow. Wageningen Academic Publishers, Wageningen, The Netherlands, pp. 147–172.

Tolkamp, B.J., D'Eath, R.B., 2016. Hunger associated with restricted feeding systems. In: Phillips, C.J.C. (Ed.), Nutrition and the Welfare of Farm Animals. Springer, Cham, Switzerland, pp. 11–27.

Tuyttens, F.A.M., 2005. The importance of straw for pig and cattle welfare: a review. Appl. Anim. Behav. Sci. 92, 261–282.
van der Peet-Schwering, C.M.C., Kemp, B., Binnendijk, G.P., den Hartog, L.A., Spoolder, H.A.M., Verstegen, M.W.A., 2003. Performance of sows fed high levels of nonstarch polysaccharides during gestation and lactation over three parities. J. Anim. Sci. 81, 2247–2258.
Van Putten, G., Van de Burgwal, J.A., 1990. Vulva biting in group-housed sows—preliminary-report. Appl. Anim. Behav. Sci. 26, 181–186.
Van Soest, P.J., 1967. Development of a comprehensive system of feed analysis and its application to forages. J. Anim. Sci. 26, 119–128.
Van Soest, P.J., Robertson, J.B., Lewis, B.A., 1991. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. J. Dairy Sci. 74, 3583–3597.
Van de Weerd, H.A., Docking, C.M., Day, J.E.L., Avery, P.J., Edwards, S.A., 2003. A systematic approach towards developing environmental enrichment for pigs. Appl. Anim. Behav. Sci. 84, 101–118.
Varel, V.H., Yen, J.T., 1997. Microbial perspective on fiber utilization by swine. J. Anim. Sci. 75, 2715–2722.
Verdon, M., Rault, J.L., 2017. Aggression in group housed sows and fattening pigs. In: Špinka, M. (Ed.), Advances in Pig Welfare. Woodhead Publishing, Duxford, UK.
Vestergaard, E.M., Danielsen, V., 1998. Dietary fibre for sows: effects of large amounts of soluble and insoluble fibres in the pregnancy period on the performance of sows during three reproductive cycles. Anim. Sci. 67, 355–362.
Veum, T.L., Crenshaw, J.D., Crenshaw, T.D., Cromwell, G.L., Easter, R.A., Ewan, R.C., Nelssen, J.L., Miller, E.R., Pettigrew, J.E., Ellersieck, M.R., 2009. The addition of ground wheat straw as a fiber source in the gestation diet of sows and the effect on sow and litter performance for three successive parities. J. Anim. Sci. 87, 1003–1012.
Weightman, R.M., Cotrill, B.R., Wiltshire, J.J.J., Kindred, D.R., Sylvester-Bradley, R., 2011. Opportunities for avoidance of land-use change through substitution of soya bean meal and cereals in European livestock diets with bioethanol coproducts. GCM Bioenergy. 3, 158–170.
Whittaker, X., Spoolder, H.A.M., Edwards, S.A., Lawrence, A.B., Corning, S., 1998. The influence of dietary fibre and the provision of straw on the development of stereotypic behaviour in food restricted pregnant sows. Appl. Anim. Behav. Sci. 61, 89–102.
Whittaker, X., Edwards, S.A., Spoolder, H.A.M., Lawrence, A.B., Corning, S., 1999. Effects of straw bedding and high fibre diets on the behaviour of floor fed group-housed sows. Appl. Anim. Behav. Sci. 63, 25–39.
Whittemore, C.T., Smith, W.C., Phillips, P., 1988. Fatness, live weight and performance responses of sows to food level in pregnancy. Anim. Sci. 47, 123–130.
Wilfart, A., Montagne, L., Simmins, P.H., van Milgen, J., Noblet, J., 2007. Sites of nutrient digestion in growing pigs: effect of dietary fiber. J. Anim. Sci. 85, 976–983.
Williams, K.W., Scott, M.M., Elmquist, J.K., 2011. Modulation of the central melanocortin system by leptin, insulin, and serotonin: co-ordinated actions in a dispersed neuronal network. Eur. J. Pharmacol. 660, 2–12.
Yde, C.C., Bertram, H.C., Theil, P.K., Knudsen, K.E.B., 2011. Effects of high dietary fibre diets formulated from by-products from vegetable and agricultural industries on plasma metabolites in gestating sows. Arch. Anim. Nutr. 65, 460–476.
Zonderland, J.J., De Leeuw, J.A., Nolten, C., Spoolder, H.A.M., 2004. Assessing long-term behavioural effects of feeding motivation in group-housed pregnant sows; what, when and how to observe. Appl. Anim. Behav. Sci. 87, 15–30.

Aggression in group housed sows and fattening pigs

8

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8.1 Introduction

Scott and Fredericson (1951) define agonistic behaviour as 'the group of behavioural adjustments associated with fighting, which includes attack, escape, threat, defence, and appeasement'. Agonistic behaviour is generally studied by measuring aggression (fight) or flight in the receiver (Jensen, 1982). Aggressive interactions between pigs are commonly considered to include the following: knock by the head (head-to-head/head-to-body knock); bite (to any part of another pig); chase; parallel and inverse parallel pressing (pressing of the shoulders against each other); and levering (lifting of the other with the head). Other agonistic behaviours include: threat (usually non-physical actions like gaze, open mouth lunges at another pig); retreat (pig moves rapidly away from another pig that is delivering aggression); and avoidance (pig moves rapidly away from another pig that is not directing any behaviour at it) (Jensen, 1980, 1982).

Under natural conditions, agonistic behaviour arises as an interplay of adaptive social strategies of individuals, thus forming the rules that govern living in social groups (Lorenz, 1966; Lindberg, 2001; East and Hofer, 2010). Periods of high aggression occur when the established social order is disrupted and this can happen frequently under the conditions imposed by commercial farming systems (Velarde, 2007). Due to the consequences of aggression on injuries, stress and productivity (Verdon et al., 2016a), and their probable links to pain and fear (Hemsworth et al., 2015), the welfare implications of aggression are obvious. The factors that contribute to the high levels of aggression observed on commercial pig farms need to be understood so that the consequences of aggression, and subsequently injuries and stress, on negative affective states, such as pain and fear, can be minimised.

The design and management of commercial group housing for pigs is complex and with wide disparity. Many features and practices can affect the frequency and duration of pig aggression, and have been reviewed elsewhere (Arey and Edwards, 1998; Barnett et al., 2001; Spoolder et al., 2009; Bench et al., 2013a,b; Verdon et al., 2015a). Rather than re-examining each of these features, this chapter discusses those aspects for which the science has been updated, is best enunciated and/or displays the most potential to reduce aggression. Furthermore, caution is recommended when applying research on immature pigs to the sow because of differences in age, experience, or physiological state (Verdon et al., 2015a). As such,

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science relating to the gilt or sow will be considered separately to that related to the weaner and grower-finisher pig.

8.2 Aggression and the dominance hierarchy

In semi-natural environments, social groups for pigs (known as a sounder) consist of 2–5 adult females, along with filial sub-adults and juveniles (Stolba and Wood-Gush, 1989; Gonyou, 2001). Aggression within a sounder is rare (Jensen, 1982; Stolba and Wood-Gush, 1989), largely due to the regulation of social interactions with an established dominance hierarchy. Sounders do not have territories and different sounders may occupy overlapping home ranges without conflict due to a strategy of mutual avoidance (Gabor et al., 1999), but aggression is common when pigs encounter unfamiliar conspecifics (Zayan, 1990).

The establishment of a dominance hierarchy in groups of unfamiliar animals involves participation in repeated contests through which individuals learn which group members an individual will likely win contests against, and which they will lose against (Lindberg, 2001; East and Hofer, 2010). These hierarchies are characterised by individual A dominating all others, individual B dominating all but individual A, individual C dominating all but individual's B and A, and so on until the most subordinate animal dominates none other (Petherick, 2010). Many individuals that live in small groups, such as sows, arrange themselves into stable linear dominance hierarchies. In group sizes that are slightly larger than those observed for the typical sounder, triangular or more complex relationships may emerge (Lindberg, 2001). Indeed, circular ($A > B > C > A$), bidirectional and rank changing dominance relationships have been reported in groups of eight young pigs (Meese and Ewbank, 1972, 1973) and groups of six (Martin and Edwards, 1994; Arey, 1999) and eight (Hoy and Bauer, 2005) sows. Thus, in this chapter, the term 'dominance hierarchy' actually refers to a loosely linear 'dominance network', that is the result of all the dyadic dominance relationships between pigs within a group.

In pigs, aggression is a key feature of the formation of a dominance hierarchy. Once the dominance relationships are established they are usually maintained by subordinate animals actively avoiding those more dominant, provided they are able to do so, rather than dominants seeking out and attacking those of lower status (Gonyou, 2001). There are three points about dominance hierarchies that need to be noted. Firstly, a hierarchy is specific to the members of a particular group, and, as such, if individuals are added to the group the hierarchy often need to reform (Ewbank, 1976). However, the dyadic relationships between familiar pigs within a group appear to withstand changes to the group composition. For instance, aggression between pairs of weaner pigs in an established group of eight does not increase when the top, middle and low-ranking pig is removed (Ewbank and Meese, 1971), nor does aggression between resident sows increase when unfamiliar sows are added to a dynamic group (Krauss and Hoy, 2011). Secondly, the rank of an individual in one group is not always indicative of the rank it will hold in another

(Lindberg, 2001). Thirdly, even in stable groups an individual's rank can change with age and/or the need or value placed on a resource being competed for (Lindberg, 2001).

There is significant variation in the literature regarding both the terminology and the methodology by which a pig's position in the hierarchy, or rank, is evaluated. For instance, rank has been assessed based on agonistic behaviour (i.e., aggression delivered and received, displacement success) observed within 3 (Couret et al., 2009), 9 (O'Connell et al., 2003), 48 (Hoy et al., 2009; Stukenborg et al., 2011; Verdon et al., 2016a) or 72 (Otten et al., 1997, 2002; Tuchscherer et al., 1998; Zhao et al., 2013) hours post-mixing, on multiple occasions throughout gestation (Mendl et al., 1992; Zanella et al., 1998; Kranendonk et al., 2007), or in paired (Brouns and Edwards, 1994; Arey, 1999) and group feeding (Rudine et al., 2007; Ison et al., 2010) competition tests. Pigs that deliver more aggression than they receive, displace others more than they are displaced themselves, or are more successful in obtaining priority access to resources (e.g., food) are typically categorised as belonging to the upper (i.e., dominant) end of the hierarchy. Conversely, pigs that deliver little to no aggression, displace no other pigs and are least successful at gaining access to priority resources are typically categorised as belonging to the lower end of the hierarchy (i.e., submissive). Some studies (Mendl et al., 1992; Zanella et al., 1998; Zhao et al., 2013; Verdon et al., 2016a) use a third classification for pigs belonging to the middle of the hierarchy (i.e., subdominant), on the basis that these pigs deliver aggression and displace other pigs, but receive more aggression or are displaced more frequently. Regardless of whether displacement success (Mendl et al., 1992) or aggressive behaviour (Verdon et al., 2016a) is used to classify the rank of gilts and sows, the majority of pigs are found to be subdominant (45%–65%), with fewer numbers of submissive (20%) and dominant (16%–34%) animals. It must be noted that, because dominance operates along a continuum, such classifications are arbitrary and variation will exist within each category of pig. Nonetheless, such classifications are useful in instances where the hierarchy has not stabilised (Mendl et al., 1992) or contains complex dominance relationships.

8.3 Aggression in commercial farms

8.3.1 Aggression post-mixing

The mixing of unfamiliar pigs is common practice at many stages of commercial pig production. Often pigs are mixed with conspecifics that are similar in age, size and sex and into group sizes much larger than the typical sounder. The first time pigs are normally mixed with unfamiliar animals is immediately following weaning with a second or third mixing occurring during the grower-finisher period. Group housed breeding sows are mixed into groups with unfamiliar conspecifics for each gestation, which equates to at least one mixing with unfamiliar sows approximately every 5 months. A dominance hierarchy is specific to a particular set of group members, and as such a new hierarchy may be reformed at each new mixing. Although influenced by design features, aggression in both young pigs and sows is reported to peak approximately 2 h after mixing, and decrease significantly thereafter as the hierarchy forms (Meese and Ewbank, 1973; Parratt et al., 2006; Schmolke et al., 2004; Mount and Seabrook, 1993). This intense period of aggression is probably due to aggressive animals fighting to stake a claim for dominance. At least in small, experimental groups of pigs, Meese and Ewbank (1973) found that the peak in aggression after mixing young pigs was almost entirely attributed to the animal that later became dominant.

Due to the frequency and severity of interactions, aggression associated with the formation of a hierarchy can be intense, however, it is also usually short-lived. The majority of fighting occurs within 2–3 days of mixing in young pigs (Puppe et al., 1997; Fels et al., 2014) and dry sows (Marchant-Forde, 2009). Due to the 'avoidance order', sows that are successful in achieving a dominant position following mixing have a reduced need to subsequently deliver aggression, resulting in an overall reduction in aggression in the group (Gonyou, 2001; Broom and Fraser, 2010).

8.3.2 Aggression once a hierarchy is formed

In comparison to aggression at mixing, aggression once a hierarchy has been formed is shorter in duration but can occur much more frequently (Spoolder et al., 2009). The nature of this aggression also differs to that observed at mixing. Aggression in established groups of pigs is more likely to involve single aggressive bouts (e.g., knocks, bites) and little to no fighting (Karlen et al., 2007), with an increased reliance on non-physical aggression, such as displacements and threats (Randolph et al., 1981).

As previously discussed, aggression post-mixing is largely attributed to aggressive animals engaging in fights for dominance (Verdon et al., 2016a). Sows that are successful at achieving a dominant status following mixing continue to deliver aggression to lower ranking conspecifics (Csermely and Wood-Gush, 1990; Brouns and Edwards, 1994; Verdon et al., 2016a). Thus, the aggressive behaviour of both gilts and sows on the day after mixing is related to their aggressive behaviour throughout gestation (Verdon et al., 2015b, 2016a).

Aggression once a hierarchy has been established typically occurs over competition for access to, or defence of, a restricted resource. For instance, while sows living under natural conditions spend up to 75% of their day foraging (Stolba and Wood-Gush, 1989), sows in commercial systems only spend 15%–24% of their time foraging (Marchant-Forde, 2009) and are restrictedly fed during gestation. With commercial gestating sows experiencing hunger for a significant period of the day, feeding becomes a major event in the life of the sow (reviewed by Verdon et al., 2015a). Indeed, after a hierarchy has been established, most of the aggression between group housed sows and growing-finishing pigs occurs around feeding (Baxter, 1983; Csermely and Wood-Gush, 1987), with dominant animals delivering the majority of this aggression (Csermely and Wood-Gush, 1990; Brouns and

Edwards, 1994; Verdon et al., 2016a). When sows have to compete for food, aggression around feeding remains high for at least 5–9 days following mixing and does not stabilise until at least 28 days following mixing (Barnett, 1997; Arey, 1999; Verdon et al., 2016a).

While competition for feed or access to feed is obviously important, competition for access to the other resources such as the drinker (Chapinal et al., 2010), foraging material (Bench et al., 2013b) or preferred lying areas (Strawford et al., 2008) can also affect aggression levels. Furthermore, frustration associated with, for example, an unpredictable environment or food restriction may also increase aggression (Dantzer et al., 1980; Carlstead, 1986; Broom and Johnson, 1993).

8.3.3 Skins lesions as a measure of aggression

The assessment of lesions on the skin, such as cuts and scratches, offers a rapid means of evaluating aggression of a large number of pigs under commercial conditions and, as such, is often used as a proxy measurement of aggression (Turner et al., 2006a,b, 2008; Schneider et al., 2007; Spoolder et al., 2009; D'Eath et al., 2010; Chapinal et al., 2010; Martin et al., 2015). Like aggression, the frequency of skin lesions peaks after mixing, declining thereafter (Arey, 1999; Anil et al., 2005; Séguin et al., 2006; Verdon et al., 2016a).

Assessment of skin lesions on individual pigs may also provide insight into the aggressive behaviour of individuals within a group. The total number of lesions sustained by growing pigs 24 h after being mixed is related to the amount of time pigs spent fighting and the amount of time pigs spent being bullied (Turner et al., 2006a). Thus, while distinguishing between pigs that fight and those that were bullied is difficult using lesion scores alone, low levels of lesions could potentially identify those that avoid aggression (Turner et al., 2006a). Assessing lesion location may allow researchers to infer how a lesion was sustained. In general, pigs that have been fighting sustain lesions to the front third of the body (Turner et al., 2006a; Stukenborg et al., 2011) while lesions associated with being bullied are concentrated on the rear part of the body (Turner et al., 2006a). A large amount of error remains unexplained when lesion occurrence and location are used to assess individual pig aggressive behaviour (Turner et al., 2006a). Consequently, caution is recommended when using the lesion scoring approach, and, when feasible, observations of aggressive behaviour should be used in preference to lesion assessment (Turner et al., 2006a).

Turner et al. (2009) found that skin lesions in finishing pigs 24 h post-mixing were positively correlated with injuries 3 weeks later, indicating that post-mixing lesions are predictive of those sustained in the longer term. In gilts and sows, however, the majority of studies report no relationship between skin lesions and sow aggressive behaviour (or social rank) early after mixing, but in the long term dominant sows sustain the fewest lesions and submissive sows sustain the most (Arey, 1999; O'Connell et al., 2003; Couret et al., 2009; Verdon et al., 2016a). Research by Tönephohl et al. (2013) suggests sows that receive more aggression after being mixed into a dynamic pen have more injuries on their head 10 weeks later.

However, lesions sustained to the middle or rear of the sow were not related to aggressive behaviour post-mixing. More research is required to validate relationships between gilt and sow aggressive behaviour post-mixing and the location of skin lesions in both the short and long term.

In this chapter, we preferentially cover studies that have directly observed aggression, rather than used skin lesions as an indirect measure of aggression. There is little doubt that aggression and injuries are related at the group level. However, the relationship between aggression and skin lesions at an individual level is more complex, and the method of using skin lesions to determine gilt and sow aggressiveness requires further validation.

8.4 Factors that affect sow aggression

8.4.1 Sow aggression around mixing

8.4.1.1 Space

Increases in floor space allowance from 1 to 2 m^2 per gilt, and 1.4 to 3.3 m^2 per sow, have no effect on aggressive behaviour for 2 h immediately following mixing (Barnett et al., 1992; Barnett, 1997; Remience et al., 2008). On the day after mixing, however, a significant body of research indicates that aggression declines as floor space allowance increases (1.0–2.0 m^2 per gilt, Barnett, 1997; 1.4–3.0 m^2 per sow, Hemsworth et al., 2013, 2016; Rault, 2016). From these results it is apparent that, irrespective of space allowance, unfamiliar sows will engage in aggression immediately following mixing in an attempt to establish dominance relationships. Thus, providing sows with enough space to allow normal social interaction patterns, including aggressive and submissive (i.e., avoidance) behaviours, may reduce the time and level of aggression required to form a hierarchy (Jensen, 1984; Barnett et al., 1992; Marchant-Forde et al., 2011; Rault, 2016). One suggestion is to provide increased space immediately after mixing and decrease space once a hierarchy has been achieved (i.e., staged-gestation penning, see Verdon et al., 2015a; Hemsworth et al., 2016). Greenwood et al. (2016) reported that providing larger floor space allowance (4.0 or 6.0 m^2 per sow) at mixing and subsequently reducing it to 2.0 m^2 per sow 4 days post-mixing did not affect aggression, but this strategy merits further research.

As space becomes more restricted, dominant sows may monopolise the preferred lying and ‘social’ areas with submissive sows avoiding interactions (Mack et al., 2014). Indeed, in pens equipped with free access stalls, more than half the sows spent less than 5% of their time in the common area, with the smallest sows spending the least amount of time out of the stalls (Rioja-Lang et al., 2013). Limited space may also inhibit the display of submissive behaviours (e.g., withdrawal, avoidance). For instance, when sows are mixed in a 5000 m^2 grassy paddock 61% of the breaks in aggressive interactions were preceded by withdrawal of one sow, but not responding to or withdrawing from dominant pigs did not diffuse interactions in indoor systems (3.2 m^2/sow, Marchant-Forde et al., 2011). This emphasises the importance of facilitating active avoidance of dominant sows by those who are subordinate, possibly through the inclusion of a solid visual barrier (see Marchant-Forde and Marchant-Forde, 2005) or access to full-body feeding stalls (Wang and Li, 2016).

8.4.1.2 Group size

The effects of group size on sow aggression early after mixing are not clear. One study reported increased aggression for 2 days post-mixing as group size increased from 5 to 40 sows (Taylor et al., 1997), whereas another study found no effect of group sizes from 30 to 80 sows on aggression on the day after mixing (Hemsworth et al., 2013). Aggression is reduced among sows that are familiar with one another (e.g., housed together in the previous 4–6 weeks, see review in Verdon et al., 2015a) and pigs can recognise between 20 and 30 individuals (O'Connell, 2009). In large group sizes individual recognition may become difficult, thus jeopardising one of the bases of the dominance hierarchy system (Estévez et al., 2007). When animals are housed in unnaturally large groups, eventually a threshold may be crossed where the risks associated with establishing dominance relationships using aggression outweigh its benefits (Estévez et al., 2007). Under these conditions physical characteristics, such as body size, might be used to establish dominance rather than aggression (e.g., D'Eath and Keeling, 2003; Rodenburg and Koene, 2007). Large groups also provide more opportunities for subordinate sows to take shelter by hiding behind others or escaping into the group (Spoolder et al., 2009).

Sows have been observed to form smaller subgroups when mixed into large groups, within each a social hierarchy operates (see Verdon et al., 2015a). Sows do appear to rest in subgroups when housed in pens of 40 animals (Moore et al., 1993; Taylor et al., 1997), and subgroups remain intact throughout gestation when they are reinforced by the provision of internal pen partitions (van Putten and van de Burgwal, 1990). Facilitating the formation of subgroups may also help to reduce aggression in dynamic housing systems (i.e., systems that regularly remove and/or introduce sows to a group). For example, Durrell et al. (2003) found that housing small numbers of sows together for a period prior to introducing them to larger established group of sows reduced aggression both within the subgroup and between resident and subgroup sows.

8.4.1.3 Individual aggressive characteristics

Individual variation in the aggressive behaviour of pigs is well documented (e.g., Mendl et al., 1992; Mount and Seabrook, 1993; Verdon et al., 2016a). High social rank is correlated with sow weight and parity, with heavier sows typically being older and more dominant, although there are exceptions (reviewed in Verdon et al., 2015a).

For gilts and sows, dominant animals deliver the most aggression and receive the least aggression throughout gestation, whereas aggression received by subdominant and submissive animals is comparable (Verdon et al., 2016a). It has been hypothesised that, when sows are fed simultaneously from the floor, subdominant sows risk receiving aggression by feeding at the same time as dominant sows, whereas submissive sows receive aggression when the floor space allowance provided does not allow for avoidance (1.8 m^2 per gilt/sow, Verdon et al., 2016a). Interestingly, subdominant sows are reported to receive more aggression than submissive animals when provided with increased space allowance (2.7 m^2 per sow; Munoz et al., 2015). Again, this highlights the importance of space in the period immediately post-mixing, particularly for the most vulnerable animals.

8.4.1.4 Genetics, repeatability and experience

Obviously, genetics is a contributing factor to individual sow aggressive behaviour (see Turner et al., 2017 Chapter 14: Breeding for pig welfare; opportunities and challenges). For gilts and sows, aggression received post-mixing is moderately heritable ($h^2 = 0.42$, Stukenborg et al., 2012) but the heritability for the delivery of severe aggression (multiple blows or bites in a continuous sequence) is low ($h^2 = 0.24$, Løvendahl et al., 2005).

Verdon et al. (2015b) found that sow aggressive behaviour was more repeatable within a gestation than between gestations, when mixed into groups with different individuals. The authors suggested that social experience and group composition contribute to the expression of the aggressive phenotype in adult pigs. This assertion is evidenced by the fact that individual sow aggressive behaviour early after mixing is less repeatable from parity 1 to 2 ($r^s = 0.5$, Verdon et al., 2015b) than from parity 2 to 3 ($r^s = 0.7$, Horback and Parsons, 2016). Increasing the social experience of gilts during adolescence by frequently regrouping them also reduced their aggressiveness after being mixed for their first gestation (van Puttan and Bure, 1997), but little is known about the potential to provide greater social experience early in life in order to minimise aggression in the adult pig (see Telkänranta and Edwards, 2017 Chapter 4: Lifetime consequences of the early physical and social environment of piglets).

When housed in groups of uniform parity, the aggressive behaviour of sows is more predictable than that of gilts (Verdon et al., 2017) and sows form a stable social hierarchy more quickly than gilts (Verdon et al., 2016a) and growing pigs (Parent et al., 2012). However, when housed in mixed parity groups, sows may also show flexibility in their use of aggression depending on the physical characteristics or behaviour of their pen mates (see Verdon et al., 2015a). Variation in age exists in natural groups of pigs (Gonyou, 2001), and such diversity may be integral to social learning and stabilisation of the social group. As stated by Verdon et al. (2015a), 'the importance of interactions with older sows in developing social skills in the female pig may be vastly underestimated'. More research is required to determine if young, vulnerable sows are better protected from aggression in single or mixed parity groups. Moreover, most research has studied the gilt as a model for sow aggression, and the aggressive behaviour of the gilt may not necessarily translate to that of multiparous sows.

8.4.1.5 Other management strategies

Other factors that may affect sow aggression at mixing include the provision of straw or rice hulls (to provide a distraction and increase foothold), the provision of food ad libitum (to reduce competition and distract sows from fighting), the presence of a boar (as a 'supradominant' boar may suppress sow aggression), the shape of the pen (to ensure sows cannot be cornered or allow for escape opportunities or hiding places), the use of masking odours (based on the theory that anosmic pigs show reduced aggression), sedation (sedated pigs will rest rather than fight) and the stage of reproduction at mixing (sow appear to be more aggressive when mixed post-insemination than after pregnancy confirmation) (reviewed in Arey and Edwards, 1998; Barnett et al., 2001; Verdon et al., 2015a). However, a large number of these methods are thought to postpone rather than reduce aggression post-mixing (Barnett et al., 2001).

8.4.2 Sow aggression once a hierarchy has been formed

Competition for feed or access to feed is of particular importance for gestating sows, which are commonly restrictively fed (see D'Eath et al., 2017 Chapter 7: Mitigating hunger in pregnant sows, for a more detailed discussion about feeding systems and hunger). The level of competition is affected by the type of feeding system used (Spoolder et al., 2009), and this is discussed below.

8.4.2.1 Floor feeding

Dropping feed directly onto the pen floor (i.e., floor feeding) requires sows to feed simultaneously. The resulting competition for access to food results in aggression immediately following feed delivery in these systems (e.g., Csermely and Wood-Gush, 1987). The feed distributed via a floor-feeding system is consumed in approximately 20 min after delivery when sows are fed once per day (Brouns and Edwards, 1994). Dominant sows monopolise the feeding area as long as feed remains present (Csermely and Wood-Gush, 1990; Rault et al., 2015), delivering the most and receiving the least aggression while doing so (Verdon et al., 2015b, 2016a). As a result, low-ranking sows have reduced feed intake and exhibit lower weight gain throughout gestation (Edwards, 1992; Verdon et al., 2016a). Feeding sows twice rather than once per day can reduce feeding motivation (Jensen et al., 2012). When the daily ration of feed is delivered over multiple bouts, aggression delivered by dominant sows and aggression received by all sows decline over subsequent feed drops (Rault et al., 2015; Verdon et al., 2015b). However, this does not correspond with increased feed intake for subordinate sows (Zegarra et al., 2017).

8.4.2.2 Individual feeding systems

There are two alternative feeding systems that are commonly used in an attempt to reduce aggression around feeding and variation in sow feed intake. The first of these are feeding stalls, which can be partial (shoulder) or full (body) length, with or without a 'locking' in mechanism. Feeding gilts in stalls, particularly full-body length stalls, reduces aggression at feeding, in comparison to floor feeding (Barnett et al., 1992; Barnett, 1997; Andersen et al., 1999). While the majority of feed delivered to sows in feeding stalls is consumed within 10 min, there is considerable individual variation in this rate of consummation with larger sows eating faster than smaller sows (Bøe and Cronin, 2015). Thus, gaining access to the feeding stalls can lead to competition and aggression (Bench et al., 2013b) and sows that finish their ration first may attempt to displace other sows from their stalls. This may explain why Andersen et al. (1999) found increased vulva bites in pens with full-body feeding stalls. It is also important to consider that simultaneous feeding of sows may precede competition for access to the drinkers, highlighting the importance of accessibility to the drinker as well as to feed (Chapinal et al., 2010).

The second common alternative to floor feeding is the electronic sow feeder (ESF). This system allows for the greatest control over individual sow intake, but forces sows to feed in sequence. This results in aggression and the displacement of subordinates as sows queue at the entrance of the feeder (Bench et al., 2013b). The design of the pen and the placement of the ESF may affect aggression in these systems. For instance, a low number of sows per ESF, a long route from exit to entry of the ESF and positioning the ESF away from busy areas or other resources (e.g., drinker, hay rack), may all help reduce aggression and improve ESF accessibility for subordinate sows (reviewed in Verdon et al., 2015a).

8.4.2.3 Hunger

Reducing sow hunger could reduce competition for feed, and consequently aggression around feeding (see D'Eath et al., Chapter 7: Mitigating hunger in pregnant sows). The evidence that a high-fibre diet will prolong satiety and reduce sow aggression is contradictory (see review Verdon et al., 2015a; Sapkota et al., 2016). Variation in the level of inclusion and type of dietary fibre as well as feeding regimes may account for these discrepancies. Increasing the quantity of feed has been more effective at reducing feeding motivation in sows than the inclusion of fibre in the diet (Jensen et al., 2012, 2015), although it does not affect aggression when sows are fed in 'lock in' stalls or in ESF systems (Spoolder et al., 1995, 1997). Alternatively, extending the time taken for sows to consume their daily ration can reduce general activity (Bergeron and Gonyou, 1997), but may cause crowding and contribute to increased aggression in an ESF system (Bench et al., 2013a).

8.4.2.4 Other managerial factors

One of the difficulties in discussing factors that may influence competition for feed is the inherent interaction between feeding regime and managerial factors or features of pen design (Bench et al., 2013a,b). For instance, when sows are mixed after pregnancy confirmation and fed individually, increasing floor space allowance reduces aggression observed approximately 7 days post-mixing (ESF, 2.25 or 3.0 m^2 per sow, Remience et al., 2008; lock-in feeding stalls for 1 h around feeding, 2.0–4.8 m^2 per sow, Weng et al., 1998). However, when sows are mixed early after insemination and are floor fed, aggression at 8–9 days post-mixing is not affected by space (1.4–3.0 m^2 per sow, Hemsworth et al., 2013, 2016; Rault, 2016).

Nonetheless, regardless of the feeding system, the effects of space allowance on gilt and sow aggression appear negligible from at least 15 days post-mixing (Barnett et al., 1992; Weng et al., 1998; Remience et al., 2008; Salak-Johnson et al., 2012; Hemsworth et al., 2013, 2016). Early after mixing, decreasing the stocking density increases the frequency of aggressive interactions (i.e., bites, head knocks and pushes) and decreases the frequency of neutral (i.e., nose contact) and non-aggressive agonistic (i.e., threats) interactions (Jensen, 1984; Rault, 2016; Weng et al., 1998), but these differences are not evident at day 9 post-mixing (Rault, 2016). Hemsworth et al. (2016) suggested that sows adapt to reduced space as the social dominance hierarchy stabilises. Thus, one explanation for these findings is that submissive sows modify their behaviour (e.g., change feeding patterns) so that they are able to avoid dominant sows, despite the reduced available space (Rault, 2016). However, that aggression delivered around feeding by gilts housed at 2.0 m^2 per gilt was lower from day 2 to 54 post-mixing than those housed at 1.0 m^2 per gilt indicates a critical lower threshold for space restriction below which gilts cannot adapt (Barnett, 1997).

The provision of foraging materials (e.g., straw, rice hulls, grass silage, mushroom compost) may increase satiation, environmental complexity and provide an outlet for exploratory behaviour. However, the effect of foraging substrates on aggression is also subject to an interaction with feeding regime (Bench et al., 2013b). Providing straw in a rack reduces aggression at the ESF but competition for access to the straw increases aggression at the rack (Krause et al., 1997; Stewart et al., 2008). When straw is provided on the ground as bedding it has no effect on aggression in systems that utilise an ESF or feeding stalls (Broom et al., 1995). This contrasts with findings when sows are floor fed, where increased substrate manipulation can lead to more encounters between sows that resulted in aggression (Whittaker et al., 1999).

8.5 Factors that affect aggression in the weaner and fattening pig

8.5.1 Aggression in the weaner and fattening pig around mixing

8.5.1.1 Weaning

Weaning is a particularly stressful time in a pig's life, with the cumulative effects of an abrupt separation from the sow, a transition from a milk to a grain based diet, mixing with unfamiliar pigs for the first time and a change of the physical environment. While there is disagreement over whether a change in environment *per se* increases aggression in recently weaned pigs, it is clear that post-weaning aggression is associated with the mixing of unfamiliar pigs (Friend et al., 1983; Hötzel et al., 2011; Colson et al., 2012), and is not related to piglet age at weaning (7−28 days old, Worobec et al., 1999; 35−50 days old, Šilerová et al., 2010) or removal of the sow (Hötzel et al., 2011; Colson et al., 2012).

8.5.1.2 Space allowance, spatial quality and group size

Little is known about the relationships between aggression in recently weaned pigs and features of pen design or management. The limited literature available suggests that aggression post-weaning is not affected by floor space allowance when pigs are mixed into pairs or small groups (0.35–0.72 m^2 per pig, Spicer and Aherne, 1987). However, group size was confounded with space allowance in this study. When space allowance is kept constant, increasing weaning group size from 6 to 12 pigs reduces the linearity of the hierarchy (Fels et al., 2014), but increases between 10 and 60 pigs has no effect on aggression for the 24 h post-mixing (O'Connell et al., 2004).

The incorporation of small boxes along the pen walls reduces the frequency of attacks for 30 min after mixing pigs at weaning by facilitating the termination of fights (McGlone and Curtis, 1985), but a solid partition has no effect on aggression up to 48 h after mixing (Olesen et al., 1996). Enriching the post-weaning environment with straw does not affect aggression at mixing (Melotti et al., 2011) but reduces aggression on the day after mixing, possibly by diverting attention the attention of the piglets (Oostindjer et al., 2011; Melotti et al., 2011).

The effect of space allowance on the aggressive behaviour of growing-finishing pigs in the period immediately following mixing requires investigation. Although only a few studies have been conducted, there is no evidence of increased aggression at mixing in large groups of growing-finishing pigs (5–20 pigs Nielsen et al., 1995; 10–80 pigs Schmolke et al., 2004). There may be a physical limit to the number of fights young pigs can engage in (Turner and Edwards, 2004) resulting in otherwise aggressive pigs adopting a low aggression strategy (Samarakone and Gonyou, 2009). Alternatively, pigs in large groups may passively assess dominance (e.g., using physical characteristics) or form subgroups (Turner and Edwards, 2004). Neither the provision of straw on the pen floor (Arey and Franklin, 1995) or the presence of food and/or water (McGlone, 1986) affect levels of aggression after mixing growing-finishing pigs.

8.5.1.3 Social experience

Social factors, such as group composition and experience during lactation, may have a greater impact on aggression after mixing pigs at weaning and in the grower-finisher stages of production than features of pen design and animal management. Although enrichment of the lactation environment (e.g., with additional space, straw and increased opportunity to interact with the sow) does not affect aggression for up to 24 h post-weaning (Chaloupková et al., 2007; Melotti et al., 2011; Martin et al., 2015; Verdon et al., 2016b), piglets from enriched lactation environments are less aggressive in a food competition test at 3 and 6 months of age (Chaloupková et al., 2007). With regard to the social environment during the lactation period, pigs that experience the most aggression and competition at the sow udder fight more frequently in the 40 min post-weaning (Skok et al., 2014). A growing body of evidence has shown that social experience, gained through interactions with unfamiliar pigs, during the lactation period reduces aggression following mixing at weaning (D'Eath, 2005; Parratt et al., 2006; Kutzer et al., 2009; Li and Wang, 2011; Kanaan et al., 2012; Bohnenkamp et al., 2013; Verdon et al., 2016b), and there is limited evidence that the benefits of such social experience continues into the growing stage of production (Li and Wang, 2011). One explanation for these findings is that socially experienced pigs appear better able to recognise their fighting ability relative to others and thus form a dominance hierarchy more quickly and with less aggression (Kanaan et al., 2012; Verdon et al., 2016b). Indeed, Büttner et al. (2015) reported that more pigs fought and the average number of fights was higher following mixing at weaning than at subsequent mixings at the grower-finisher stage of production and as gilts. Other studies have also found that recently weaned pigs deliver more aggression than growing-finishing pigs (Stukenborg et al., 2011) and that aggression between growing-finishing pigs declines over subsequent mixings (Giersing and Andersson, 1998; Coutellier et al., 2007).

8.5.1.4 Group composition

Although manipulating the group composition by sex (single vs mixed-sex groups), familiarity (50% vs 16% of pigs in the pen being familiar) and weight (homogenous vs heterogeneous groups) did not affect the strength and linearity of the hierarchy (Fels et al., 2014), these factors still appear to have implications for pig aggression post-weaning.

For both weaner and growing-finishing pigs, aggression is lower when there is large disparity in weight, either between a dyad or within a group (Rushen, 1987; Moore et al., 1994; Andersen et al., 2000; Schmolke et al., 2004). Thus, mixing pigs into groups of heterogeneous weight may be one strategy to reduce aggression post-mixing. To the best of our knowledge, comparisons of aggression in groups of pigs that are homogenous or heterogeneous in weight have not been made. Such studies are required because of the possible implications that heterogeneous weight groups could have for the smallest piglets in the pen, particularly in terms of aggression received and access to resources. When in homogenous groups, light groups of weaner pigs fight less than groups of medium or heavy weaner pigs (Bohnenkamp et al., 2013), but the same comparisons are yet to be made in the growing-finishing pig.

Both barrow and female single-sex groups are less aggressive post-weaning than mixed-sex groups (Colson et al., 2006). However, in mixed-sex groups barrow piglets are more aggressive post-weaning than females (Colson et al., 2006). For growing-finishing pigs, aggression on the day of mixing does not differ between single-sex groups of female pigs and barrows, but females fight more the day after mixing (Stookey and Gonyou, 1994). While one study found barrows in mixed-sex groups to initiate more aggressive interactions than female growing pigs (Giersing and Andersson, 1998), another has reported less aggression in barrows when housed with females (Meunier-Salaün et al., 1987).

In small groups of recently weaned pigs ($n = 6$), aggression on the day of mixing decreases as the number of familiar pigs in the pen increases (range 50%–83%, Mei et al., 2016). Blackshaw et al. (1987) also found that aggression immediately after mixing weaned piglets into groups of 12 pigs was lowest when piglets from three litters were mixed, rather from two or four litters, due to the pigs making less physical contact. The effects of familiarity are no longer apparent on the day after mixing weaning pigs (Mei et al., 2016). Similar to the recently weaned pig, increasing the number of familiar growing-finishing pigs in the pen reduces aggression for 5 days post-mixing (range 25%–50% familiar pigs, Arey and Franklin, 1995). Indeed, after mixing growing-finishing pigs into groups containing both familiar and unfamiliar animals, aggression is reported to be lower between the familiar pigs than it is between the unfamiliar pigs (Giersing and Andersson, 1998; Li and Wang, 2011).

It is important to keep in mind that most studies on weaner and growing-finishing pigs have used small group sizes, and whether the findings translate to the social dynamics in much larger group sizes kept in commercial farms remain unknown (reviewed in Turner and Edwards, 2004).

8.5.2 Aggression in the weaner and fattening pig once a hierarchy has been formed

8.5.2.1 Space allowance and group size

Increasing space allowance does not affect aggression between weaner pigs 9 days post-mixing (0.35–0.72 m^2 per pig, Spicer and Aherne, 1987), although it does reduce competition at the feeder (0.32–0.64 m^2 per pig, Wolter et al., 2000). With regard to group size, Andersen et al. (2004) found that groups of 6 and 12 pigs showed more aggression 1 week post-mixing than groups of 24 weaned pigs. The authors hypothesised that the probability of being able to monopolise resources diminishes as group size increases, and thus fewer pigs engage in aggression.

Studies on the relationship between floor space allowance and aggression in growing-finishing pigs vary considerably in terms of the age and housing conditions of pigs. When group size is controlled for, general levels of agonistic behaviour between growing-finishing pigs increases as space allowance decreases (0.56–1.19 m^2/pig, Ewbank and Bryant, 1972), but space allowance does not affect aggression related to competition for feed (Ewbank and Bryant, 1972; Meunier-Salaün et al., 1987; Scollo et al., 2014). Group size also does not appear to affect the number of displacements at the feeder (range 5–20 pigs/pen, Nielsen et al., 1995). As is seen in sows (Section 8.4.1), space allowance (0.33–0.64 m^2/pig) has a greater effect than group size (range 5–20 pigs/pen) on the aggressive behaviour of growing-finishing pigs, and there is no interaction between the two variables (Randolph et al., 1981).

8.5.2.2 Feeder design

As stated by O'Connell (2009), 'the requirements of pigs in terms of feeder design are more critical in the post-weaning period than in any other period in life'. However, there are few rigorous recommendations on feeder design for weaner pigs.

While mixing feed with water and feeding piglets simultaneously from troughs increases feed intake, this feeding arrangement also leads to competition and aggression at the feeder (O'Connell, 2009). Having 3−4 partitions or feeder holes along the feeding trough (i.e., multi-space feeder) and feeding piglets dry feed reduces competition at the feeder, in comparison to a multi-space feeder with wet feed, a communal trough and a single-spaced, partially enclosed feeder (O'Connell et al., 2002). Increasing the number of feeder spaces per pig reduces competition for the feeder and time spent feeding (Wolter et al., 2002; He et al., 2016). Similarly, for growing-finishing pigs, increasing the number of feeders reduces displacements at the feeder and increases feeding opportunities for small and/or submissive pigs (Hansen et al., 1982; Morrow and Walker, 1994; Botermans et al., 2000).

8.5.2.3 Enrichment

Environmental enrichment of the pre- and post-weaning pen may be more successful at reducing aggression once a hierarchy has been established than it does at mixing. For instance, Oostindjer et al. (2011) found that enrichment of the lactation pen *per se* had few effects on piglet social behaviour post-weaning, but affected how a piglet experienced an enriched (i.e., increase space, bedding and manipulative materials) or barren post-weaning environment. Weaned piglets provided with a robust 'toy' have been found to be less aggressive in the 3 weeks post-mixing, regardless of whether this object was hung from the ceiling, on the pen floor or in a fixed location (Schaefer et al., 1990; Blackshaw et al., 1997). However, such objects had no effect on aggression around the feeder (Schaefer et al., 1990). The provision of a 'toy' might distract weaner piglets from performing other behaviours, such as aggression, at times other than at feeding. A number of studies have provided rootable substrates to growing-finishing pigs in an attempt to reduce aggression, with little success (straw, logs and branches Petersen et al., 1995; peat moss, straw rack, polyurethane and paper strips Beattie et al., 1996; straw bedding or straw in a rack Fraser et al., 1991). However, a more recent study looked at the presence and characteristics of straw on aggression in growing-finishing pigs, finding that the provision of straw reduced aggression, regardless of its length (Day et al., 2008). Research by Van de Weerd et al. (2006) reports that a full bed of straw is the most effective way of occupying pigs' time, but point source enrichment objects (e.g., feed or straw dispensers, toys) are a good substitute when bedding cannot be provided. Indeed, suspending a block of hard wood over the pen appears to reduce aggression between growing-finishing pigs (Cornale et al., 2015), but increasing the number of items provided does not necessarily correspond to further reductions (Scott et al., 2007).

Thus, for weaner and grower pigs, it appears that enriching the environment through the provision of a rootable substrate or, if substrate is not available, a point source enrichment can reduce aggression. Although the exact mechanisms are unclear, environmental enrichment may reduce aggression by providing a distraction for pigs, an outlet for highly motivated behaviour (e.g., foraging, rooting) or opportunities for the pig to express control over its environment. Pigs can easily lose interest in point enrichment sources such as 'toys' (van de Weerd et al., 2006), so considerations of the novelty, accessibility and availability of an enrichment as well as its relevance to pigs is required if it is to effectively reduce aggression.

It is important to note that manipulative and potentially injurious social behaviours such as tail-biting (see Valros, 2017 Chapter 5: Tail biting) and belly nosing do not appear to be related to aggression but rather to exploratory or feeding activities (O'Connell, 2009).

8.6 Conclusions

Aggression evolved as an adaptive behaviour for the social life of pigs, facilitating the establishment of a dominance hierarchy for stable groups. However, high levels or prolonged aggression remains a major welfare issue for pigs kept in commercial pig farms. It is unlikely that pig aggression will be eliminated as long as unfamiliar pigs are frequently mixed and resources (particularly food and space) are limited. However, aggressive behaviour in pigs can be modulated by numerous internal and external factors, such as the age and previous experience of the animal, floor space allowance, feeding regimen, the time after mixing, group composition, housing design and management.

8.7 Future trends

Genetic selection for less aggressive pigs should be promoted (see Turner et al., Chapter 14: Breeding for pig welfare; opportunities and challenges), but will likely not express its full potential without further understanding of the influence of socio-behavioural development on aggression phenotype. Consequently, housing design and management practices that accommodate the development and expression of pigs' social behaviour are required. Research into strategies to reduce competition for feed and other resources, and that allow for escape or active avoidance, is also required. In particular, attention needs to be paid to the implications of such strategies for the welfare of the most submissive pigs. Despite a substantial body of research, aggression remains a key welfare topic for commercial pig farming. However, it is important to remember that aggression is just one aspect of the social behavioural repertoire of pigs. For overall improvement in pig welfare, there needs to be a focus on promoting a positive social environment in addition to reducing negative interactions, such as aggression. Given the move to group housing systems worldwide and the trend for larger group sizes, maintaining functional social groups will continue to be a challenge.

Abbreviation

ESF electronic sow feeder

References

Andersen, I.L., Boe, K.E., Kristiansen, A.L., 1999. The influence of different feeding arrangements and food type on competition at feeding in pregnant sows. Appl. Anim. Behav. Sci. 65, 91–104.

Andersen, I., Andenæs, H., Bøe, K.E., Jensen, P., Bakken, M., 2000. The effects of weight asymmetry and resource distribution on aggression in groups of unacquainted pigs. Appl. Anim. Behav. Sci. 68, 107–120.

Andersen, I.L., Nævdal, E., Bakken, M., Bøe, K.E., 2004. Aggression and group size in domesticated pigs, Sus Scrofa: 'when the winner takes it all and the loser is standing small'. Anim. Behav. 68, 965–975.

Anil, S.S., Anil, L., Deen, J., 2005. Evaluation of patterns of removal and associations among culling because of lameness and sow productivity traits in swine breeding herds. J. Am. Vet. Med. Assoc. 226, 956–961.

Arey, D.S., Franklin, M.F., 1995. Effects of straw and unfamiliarity on fighting between newly mixed growing pigs. Appl. Anim. Behav. Sci. 45, 23–30.

Arey, D.S., Edwards, S.A., 1998. Factors influencing aggression between sows after mixing and the consequences for welfare and production. Livest. Prod. Sci. 56, 61–70.

Arey, D.S., 1999. Time course for the formation and disruption of social organisation in group-housed sows. Appl. Anim. Behav. Sci. 62, 199–207.

Barnett, J.L., 1997. Modifying the design of group pens with individual feeding places affects the welfare of pigs. In: Proceedings of the 5th International Symposium American Society of Agricultural Engineers, St Joseph, Michigan, USA. pp. 613–618.

Barnett, J.L., Hemsworth, P.H., Cronin, G.M., Newman, E.A., McCallum, T.H., Chilton, D., 1992. Effects of pen size, partial stalls and method of feeding on welfare related behavioral and physiological responses of group housed pigs. Appl. Anim. Behav. Sci. 34, 207–220.

Barnett, J.L., Hemsworth, P.H., Cronin, G.M., Jongman, E.C., Hutson, G.D., 2001. A review of the welfare issues for sows and piglets in relation to housing. Aust. J. Agric. Res. 52, 1–28.

Baxter, M.R., 1983. Feeding and aggression in pigs. Appl. Anim. Ethol. 11, 74 (abstract).

Beattie, V.E., Walker, N., Sneddon, I.A., 1996. An investigation of the effect of environmental enrichment and space allowance on the behaviour and production of growing pigs. Appl. Anim. Behav. Sci. 48, 151–158.

Bench, C.J., Rioja-Lang, F.C., Hayne, S.M., Gonyou, H.W., 2013a. Group gestation housing with individual feeding I: How feeding regime, resource allocation and genetic factors affect sow welfare. Livest. Sci. 152, 208–217.

Bench, C.J., Rioja-Lang, F.C., Hayne, S.M., Gonyou, H.W., 2013b. Group gestation sow housing with individual feeding II: How space allowance, group size and composition and flooring affect sow welfare. Livest. Sci. 152, 218–227.

Bergeron, R., Gonyou, H.W., 1997. Effects of increasing energy intake and foraging behaviours on the development of stereotypies in pregnant sows. Appl. Anim. Behav. Sci. 53, 259–270.

Blackshaw, J.K., Bodero, D.A.V., Blackshaw, A.W., 1987. The effect of group composition on behaviour and performance of weaned pigs. Appl. Anim. Behav. Sci. 19, 73–80.

Blackshaw, J.K., Thomas, F.J., Lee, J.-A., 1997. The effect of a fixed or free toy on the growth rate and aggressive behaviour of weaned pigs and the influence of hierarchy on intial investigation of the toys. Appl. Anim. Behav. Sci. 53, 203–212.

Bøe, K.E., Cronin, G.M., 2015. Individual variation in eating speed of dry sows. J. Anim. Sci. 93, 1881−1886.

Bohnenkamp, A.-L., Traulsen, I., Meyer, C., Müller, K., Krieter, J., 2013. Comparison of growth performance and agonistic interaction in weaned piglets of different weight classes from farrowing systems with group or single housing. Animal. 7, 309−315.

Botermans, J.A.M., Georgsson, L., Weström, B.R., Olsson, A.-C., Svendsen, J., 2000. Effeect of feeding environment on performance, injuries, plasma cortisol and behaviour in growing-finishing pigs: studies on individual pigs housed in groups. Acta Agric. Scand. Sect. A: Anim. Sci. 50, 250−262.

Broom, D.M., Fraser, A.F., 2010. Domestic Animal Behaviour and Welfare. 4th ed. CAB International, Oxfordshire, UK.

Broom, D.M., Johnson, K.G., 1993. Stress and Animal Welfare. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Broom, D.M., Mendl, M.T., Zanella, A.J., 1995. A comparison of the welfare of sows in different housing conditions. Anim. Sci. 61, 369−385.

Brouns, F., Edwards, S.A., 1994. Social rank and feeding behaviour of group-housed sows fed competitively or ad-libitum. Appl. Anim. Behav. Sci. 39, 215−223.

Büttner, K., Scheffler, K., Czycholl, I., Krieter, J., 2015. Network characteristics and development of social structure of agonistic behaviour in pigs across three repeated rehousing and mixing events. Appl. Anim. Behav. Sci. 168, 24−30.

Carlstead, K., 1986. Predictability of feeding—its effect on agonistic behavior and growth in grower pigs. Appl. Anim. Behav. Sci. 16, 25−38.

Chaloupková, H., Illmann, G., Bartoš, L., Špinka, M., 2007. The effect of pre-weaning housing on the play and agonistic behaviour of domestic pigs. Appl. Anim. Behav. Sci. 103, 25−34.

Chapinal, N., de la Torre, J.L.R., Cerisuelo, A., Gasa, J., Baucells, M.D., Coma, J., Vidal, A., Manteca, X., 2010. Evaluation of welfare and productivity in pregnant sows kept in stalls or in 2 different group housing systems. J. Vet. Behav.-Clin. Appl. Res. 5, 82−93.

Colson, V., Orgeur, P., Courboulay, V., Dantec, S., Foury, A., Morméde, P., 2006. Grouping piglets by sex at weaning reduces aggressive behaviour. Appl. Anim. Behav. Sci. 97, 152−171.

Colson, V., Martin, E., Orgeur, P., Prunier, A., 2012. Influence of housing social changes on growth, behaviour and cortisol in piglets at weaning. Physiol. Behav. 107, 59−64.

Cornale, P., Macchi, E., Miretti, S., Renna, M., Lussiana, C., Perona, G., Mimosi, A., 2015. Effects of stocking density and environmental enrichment on behaviour and fecal corticosteroid levels of pigs under commercial farm conditions. J. Vet. Behav. 10, 569−576.

Couret, D., Otten, W., Puppe, B., Prunier, A., Merlot, E., 2009. Behavioural, endocrine and immune responses to repeated social stress in pregnant gilts. Animal. 3 (1), 118−127. Available from: http://dx.doi.org/10.1017/S1751731108003236.

Coutellier, L., Arnould, C., Boissy, A., Orgeur, P., Prunier, A., Vessier, I., Meunier-Salaün, M.-C, 2007. Pig's responses to repeated social regrouping and relocation during the growing-finishing period. Appl. Anim. Behav. Sci. 105, 102−114.

Csermely, D., Wood-Gush, D.G.M., 1987. Aggressive behaviour of grouped sows in different contexts. Appl. Anim. Behav. Sci. 17, 368−369.

Csermely, D., Wood-Gush, D.G.M., 1990. Agonistic behaviour in grouped sows. II. How social rank affects feeding and drinking behaviour. Ital. J. Zool. 57, 55−58.

Dantzer, R., Arnone, M., Mormede, P., 1980. Effects of frustration on behaviour and plasma corticosteroid levels in pigs. Physiol. Behav. 24, 1−4.

Day, J.E.L., Van de Weerd, H.A., Edwards, S.A., 2008. The effect of varying lengths of straw bedding on the behaviour of growing pigs. Appl. Anim. Behav. Sci. 109, 249−260.

D'Eath, R.B., 2005. Socialising piglets before weaning improves social hierarchy formation when pigs are mixed post-weaning. Appl. Anim. Behav. Sci. 93, 199−211.

D'Eath, R.B., Keeling, L.J., 2003. Social discrimination and aggression by laying hens in large groups: from peck orders to social tolerance. Appl. Anim. Behav. Sci. 84, 197−212.

D'Eath, R.B., Turner, S.P., Kurt, E., Evans, G., Tholking, L., Looft, H., Wimmers, K., Murani, E., Klont, R., Foury, A., Ison, S.H., Lawrence, A.B., Mormede, P., 2010. Pigs' aggressive temperament affects pre-slaughter mixing aggression, stress and meat quality. Animal. 4, 604−616.

D'Eath, R.B., Jarvis, S., Baxter, E.M., Houdijk, J., 2017. Mitigating hunger in pregnant sows. In: Špinka, M. (Ed.), Advances in Pig Welfare. Woodhead Publishing, Duxford, UK.

Durrell, J.L., Beattie, V.E., Sneddon, I.A., Kilpatrick, D., 2003. Pre-mixing as a technique for facilitating subgroup formation and reducing sow aggression in large dynamic groups. Appl. Anim. Behav. Sci. 84, 89−99.

East, M.L., Hofer, H., 2010. Social environments, social tactics and their fitness consequences in complex mammalian societies. In: Szekély, T., Moore, A.J., Komdeur, J. (Eds.), Social Behaviour: Genes, Ecology and Evolution. Cambridge University Press, Cambride, UK, pp. 360−394.

Edwards, S.A., 1992. Scientific perspectives on loose housing systems for dry sows. Pig Vet. J. 28, 40−51.

Estévez, I., Andersen, I., Nævdal, E., 2007. Group size, density and social dynamics in farm animals. Appl. Anim. Behav. Sci. 103, 185−204.

Ewbank, R., 1976. Social hierarchy in suckling and fattening pigs—review. Livest. Prod. Sci. 3, 363−372.

Ewbank, R., Meese, G.B., 1971. Aggressive behaviour in groups of domesticated pigs on removal and return of individuals. Anim. Prod. 13, 685−693.

Ewbank, R., Bryant, M.J., 1972. Aggressive behaviour amonst groups of domesticated pigs ept at various stocking rates. Anim. Behav. 20, 21−28.

Fels, M., Hartung, J., Hoy, S., 2014. Social hierarchy formation in piglets mixed in different group compositions after weaning. Appl. Anim. Behav. Sci. 152, 17−22.

Fraser, D., Phillips, P.A., Thompson, B.K., Tennessen, T., 1991. Effect of straw on the behaviour of growing pigs. Appl. Anim. Behav. Sci. 30, 307−318.

Friend, T.H., Knabe, D.A., Tanksley Jr., T.D., 1983. Behaviour and performance of pigs grouped by three different methods at weaning. J. Anim. Sci. 57, 1406−1411.

Gabor, T.M., Hellgren, E.C., Van den Bussche, R.A., Silvy, N.J., 1999. Demography, sociospatial behaviour and genetics of feral pigs (*Sus scrofa*) in a semi-arid environment. J. Zool. 247, 311−322.

Giersing, M., Andersson, A., 1998. How does former acquanitance affect aggressive behaviour in repeatedly mixed male and female pigs. Appl. Anim. Behav. Sci. 59, 297−306.

Gonyou, H.W., 2001. The social behaviour of pigs. In: Keeling, L.J., Gonyou, H.W. (Eds.), Social Behaviour in Farm Animals. CAB International, Wallingford, Oxon, UK, pp. 147−168.

Greenwood, E.C., Plush, K.J., van Wettere, W.H.E.J., Hughes, P.E., 2016. Group and indiviudal sow behaviour is altered in early gesation by space allowance in the days immediately following grouping. J. Anim. Sci. 94, 385−393.

Hansen, L.L., Hagelsø, A.M., Madsen, A., 1982. Behavioural results and performance of bacon pigs fed ‘ad libitum’ from one or several self-feeders. Appl. Anim. Ethol. 8, 307–333.

He, Y., Cui, S., Deen, J., Shurson, G.C., Li, Y., 2016. Effects of feeder space allowance on behaviour of slow-growing pigs during the nursery period. J. Anim. Sci. 94, 4. Available from: http://dx.doi.org/10.2527/msasas2016-009 (abstract).

Hemsworth, P.H., Rice, M., Nash, J., Giri, K., Butler, K.L., Tilbrook, A.J., Morrison, R.S, 2013. Effects of group size and floor space allowance on grouped sows: aggression, stress, skin injuries and reproductive performance. J. Anim. Sci. 91, 4953–4964.

Hemsworth, P.H., Mellor, D.J., Cronin, G.M., Tilbrook, A.J., 2015. Scientific assessment of animal welfare. N. Z. Vet. J. 63, 24–30.

Hemsworth, P.H., Morrison, R., Tilbrook, A., Butler, K., Rice, M., Moeller, S., 2016. Effects of floor space on the welfare of group housed sows. J. Anim. Sci. 94, 4809–4818.

Horback, K.M., Parsons, T.D., 2016. Temporal stability of personality traits in group-housed gestating sows. Animal. 10, 1351–1359. Available from: http://dx.doi.org/10.1017/S1751731116000215.

Hötzel, M.J., de Souza, G.P.P., Dalla Costa, O.A., Machado Filho, L.C.P., 2011. Disentangling the effects of weaning stresors on piglets’ behaviour and feed intake: changing the housing and social environment. Appl. Anim. Behav. Sci. 135, 44–50.

Hoy, S., Bauer, J., 2005. Dominance relationships between sows dependent on the time interval between separation and reunion. Appl. Anim. Behav. Sci. 90, 21–30.

Hoy, S., Bauer, J., Borberg, C., Chonsch, L., Weirich, C., 2009. Impact of rank position on fertility of sows. Livest. Sci. 126, 69–72.

Ison, S.H., D’Eath, R.B., Robson, S.K., Baxter, E.M., Ormandy, E., Douglas, A.J., Russell, J.A., Lawrence, A.B., Jarvis, S., 2010. Subordination style’ in pigs? The response of pregnant sows to mixing stress affects their offspring’s behaviour and stress reactivity. Appl. Anim. Behav. Sci. 124, 16–27.

Jensen, M.B., Pedersen, L.J., Theil, P.K., Yde, C.C., Bach Knudsen, K.E., 2012. Feeding motivation and plasma metabolites in pregnant sows fed diets rich in dietary fibre either once or twice daily. J. Anim. Sci. 90, 1910–1919.

Jensen, M.B., Pedersen., L.J., Theil, P.K., Knudsen, K.E.B., 2015. Hunger in pregnant sows: effects of a fibrous diet and free access to straw. Appl. Anim. Behav. Sci. 171, 81–87.

Jensen, P., 1980. An ethogram of social interaction patterns in group-housed dry sows. Appl. Anim. Ethol. 6, 341–350.

Jensen, P., 1982. An analysis of agonistic interaction patterns in group-housed dry sows—aggression regulation through an avoidance order. Appl. Anim. Ethol. 9, 47–61.

Jensen, P., 1984. Effects of confinement on social interaction patterns in dry sows. Appl. Anim. Behav. Sci. 12, 93–101.

Kanaan, V.T., Lay Jr., D.C., Richert, B.T., Pajor, E.A., 2012. Increasing the frequency of co-mingling piglets during the lactation period alters the development of social behaviour before ad after weaning. J. Appl. Anim. Welfare Sci. 15, 163–180.

Karlen, G.A.M., Hemsworth, P.H., Gonyou, H.W., Fabrega, E., Strom, A.D., Smits, R.J., 2007. The welfare of gestating sows in conventional stalls and large groups on deep litter. Appl. Anim. Behav. Sci. 105, 87–101.

Kranendonk, G., Van der Mheen, H., Fillerup, M., Hopster, H., 2007. Social rank of pregnant sows affects their body weight gain and behavior and performance of the offspring. J. Anim. Sci. 85, 420–429.

Krause, M., Vant Klooster, C.E., Bure, R.G., Metz, J.H.M., Sambraus, H.H., 1997. The influence of sequential and simultaneous feeding and the availability of straw on the behaviour of gilts in group housing. Netherlands J. Agric. Sci. 45, 33–48.

Krauss, V., Hoy, S., 2011. Dry sows in dynamic groups: an investigation of social behaviour when introducing new sows. Appl. Anim. Behav. Sci. 130, 20–27.

Kutzer, T., Bünger, B., Kjaer, J.B., Schrader, L., 2009. Effects of early contact between non-littermate piglets and of the complexity of farrowing conditions on social behaviour and weight gain. Appl. Anim. Behav. Sci. 121, 16–24.

Li, Y., Wang, L., 2011. Effects of previous housing system on agonistic behaviors of growing pigs at mixing. Appl. Anim. Behav. Sci. 132, 20–26.

Lindberg, A.C., 2001. Group life. In: Keeling, L.J., Gonyou, H.W. (Eds.), Social Behaviour in Farm Animals. CAB International, Oxfordshire, UK, pp. 37–58.

Lorenz, K., 1966. On Aggression (English translation). Routledge, Oxon, UK.

Løvendahl, P., Damgaard, L.H., Nielsen, B.L., Thodberg, K., Su, G., Rydhmer, L., 2005. Aggressive behaviour of sows at mixing and maternal behaviour are heritable and genetically correlated traits. Livest. Prod. Sci. 93, 73–85.

Mack, L.A., Lay, D.D., Eicher, S.D., Johnson, A.K., Richert, B.T., Pajor, E.A., 2014. Group space allowance has little effect on sow healthy, productivity, or welfare in a free-access stall system. J. Anim. Sci. 92, 2554–2567. Available from: http://dx.doi.org/10.2527/jas2013-7352.

Marchant-Forde, J.N., 2009. Welfare of dry sows. In: Marchant-Forde, J.N. (Ed.), The Welfare of Pigs. Springer, New York, NY, pp. 95–139.

Marchant-Forde, J.N., Marchant-Forde, R.M., 2005. Minimizing inter-pig aggression during mixing. Pig News Info. 26, 63N–71N.

Marchant-Forde, J.N., Garner, J.P., Lay Jr., D.C., Johnson, A.K., 2011. Action-reaction: using Markov analysis to elucidate social behaviour when unacquainted sows are mixed. In: Proceedings of the 45th Congress of the International Society for Applied Ethology. Indianapolis, USA, 31 July–4 August. pp. 71 (abstract).

Martin, J.E., Edwards, S.A., 1994. Feeding behavior of outdoor sows—the effects of diet quantity and type. Appl. Anim. Behav. Sci. 41, 63–74.

Martin, J.E., Ison, S.H., Baxter, E.M., 2015. The influence of neonatal environment on piglet play behaviour and post-weaning social and cognitive development. Appl. Anim. Behav. Sci. 163, 69–79.

McGlone, J.J., 1986. Influence of resources on pig aggression and dominance. Behav. Process. 12, 135–144.

McGlone, J.J., Curtis, S.E., 1985. Behaviour and performance of weanling pigs in pens equipped with hide areas. J. Anim. Sci. 60, 20–24.

Meese, G.B., Ewbank, R., 1972. A note on instability of the dominance hierarchy and variations in level of aggression within groups of fattening pigs. Anim. Prod. 14, 339–362.

Meese, G.B., Ewbank, R., 1973. Establishment and nature of dominance hierarchy in domesticated pig. Anim. Behav. 21, 326–334.

Mei, H., Yang, B., Luo, J., Gan, L., 2016. The effect of mixing levels on aggression at weaning in piglets. Appl. Anim. Behav. Sci. 179, 32–38.

Melotti, L., Oostindjer, M., Bolhuis, J.E., Held, S., Mendl, M., 2011. Coping personality type abnd environmental enrichment affect aggression at weaning in pigs. Appl. Anim. Behav. Sci. 133, 144–153.

Mendl, M., Zanella, A.J., Broom, D.M., 1992. Physiological and reproductive correlates of behavioral strategies in female domestic pigs. Anim. Behav. 44, 1107–1121.

Meunier-Salaün, M.C., Vantrimponte, M.N., Raab, A., Dantzer, R., 1987. Effect of floor area restriction upon performance, behaviour and physiology of growing-finishing pigs. J. Anim. Sci. 64, 1371–1377.

Moore, A.S., Gonyou, H.W., Ghent, A.W., 1993. Integration of newly introduced and resident sows following grouping. Appl. Anim. Behav. Sci. 38, 257–267.

Moore, A.S., Gonyou, H.W., Stookey, J.M., McLaren, D.G., 1994. Effect of group composition and pen size on behaviour, productivity and immune response of growing pigs. Appl. Anim. Behav. Sci. 40, 13–30.

Morrow, A.T.S., Walker, N., 1994. Effects of number and siting of single-space feeders on performance and feeding behaviour of growing pigs. J. Agric. Sci. 122, 465–470.

Mount, N.C., Seabrook, M.F., 1993. A study of aggression when group housed sows are mixed. Appl. Anim. Behav. Sci. 36, 377–383.

Munoz, C., Hemsworth, P.H., Jongman, E., 2015. A study of agonistic strategies after mixingin group housed sows. Anim. Prod. Sci. 55, 1488 (abstract).

Nielsen, B.L., Lawrence, A.B., Whittemore, C.T., 1995. Effect of group size on feeding behaviour, social behaviour and performance of growing pigs using single-space feeders. Livest. Prod. Sci. 44, 73–85.

O'Connell, N.E., 2009. Housing the fattening pig. In: Marchant-Forde, J.N. (Ed.), TheWelfare of Pigs. Springer, New York, NY, pp. 189–210.

O'Connell, N.E., Beattie, V.E., Weatherup, R.N., 2002. Influence of feeder type on the performance and behaviour of weaned pigs. Livest. Prod. Sci. 74, 13–17.

O'Connell, N.E., Beattie, V.E., Moss, B.W., 2003. Influence of social status on the welfare of sows in static and dynamic groups. Anim. Welfare. 12, 239–249.

O'Connell, N.E., Beattie, V.E., Weatherup, R.N., 2004. Influence of group size during the post-weaning period on the performance and behaviour of pigs. Livest. Prod. Sci. 86, 225–232.

Olesen, L.S., Nygaard, C.M., Friend, T.H., Bushong, D., Knabe, D.A., Vestergaard, K.S., Vaughan, R.K., 1996. Effect of partitioning pens on aggressive behaviour of pigs regrouped at weaning. Appl. Anim. Behav. Sci. 46, 167–174.

Oostindjer, M., van den Brand, H., Kemp, B., Bolhuis, J.E., 2011. Effects of environmental enrichment and loose housing of lactating sows on piglet behaviour before and after weaning. Appl. Anim. Behav. Sci. 134, 31–41.

Otten, W., Puppe, B., Stabenow, B., Kanitz, E., Schön, P.C., Brüssow, K.P., Nürnberg, G., 1997. Agonistic interactions and physiological reactions of top-and bottom-ranking pigs confronted with a familiar and an unfamiliar group: preliminary results. Appl. Anim. Behav. Sci. 55, 79–90.

Otten, W., Puppe, B., Kanitz, E., Schon, P.C., Stabenow, B., 2002. Physiological and behavioral effects of different success during social confrontation in pigs with prior dominance experience. Physiol. Behav. 75, 127–133.

Parent, P., Meunier-Salaün, M.-C., Vasseur, E., Bergeron, R., 2012. Stability of social hierarchy in growing female pigs and pregnant sows. Appl. Anim. Behav. Sci. 142, 1–10.

Parratt, C.A., Chapman, K.J., Turner, C., Jones, P.H., Mendl, M.T., Miller, B.G., 2006. The fighting behaviour of piglets mixed before and after weaning in the presence or absence of a sow. Appl. Anim. Behav. Sci. 101, 54–67.

Petersen, V., Simonsen, H.B., Lawson, L.G., 1995. The effect of environmental stimulation on the development of behaviour in pigs. Appl. Anim. Behav. Sci. 45, 215–224.

Petherick, J.C., 2010. Hierarchy. In: Mills, D.S., et al., (Eds.), The Encyclopedia of Applied Animal Behaviour and Welfare. CAB International, Oxfordshire, UK, pp. 315–316.

Puppe, B., Tuchscherer, M., Tuchscherer, A., 1997. The effect of housing conditions and social environment immediately after weaning on the agonistic behaviour, neutrophil/lymphocyte ratio and plasms glucose levels in pigs. Livest. Prod. Sci. 48, 157–164.

Randolph, J.H., Cromwell, G.L., Stahly, T.S., Kratzer, D.D., 1981. Effects of group size and space allowance on performance and behaviour of swine. J. Anim. Sci. 53, 922–927.

Rault, J.-L., 2016. Social interaction patterns according to stocking density and time post-mixing in group-housed gestating sows. Anim. Prod. Sci. Available from: http://dx.doi.org/10.1071/AN15415.

Rault, J.-L., Ho, H., Verdon, M., Hemsworth, P., 2015. Feeding behaviour, aggression and dominance in group-housed sows. Anim. Prod. Sci. 55, 1495 (abstract).

Remience, V., Wavreille, J., Canart, B., Meunier-Salaün, M.-C., Prunier, A., Bartiaux-Thill, N., Nicks, B., Vandenheede, M., 2008. Effects of space allowance on the welfare of dry sows kept in dynamic groups and fed with an electronic sow feeder. Appl. Anim. Behav. Sci. 112, 284–296.

Rioja-Lang, F.C., Hayne, S.M., Gonyou, H.W., 2013. The effect of pen design on free space utilization of sows group housed in gestation pens equipped with free access stalls. Appl. Anim. Behav. Sci. 148, 93–98.

Rodenburg, B., Koene, P., 2007. The impact of group size on damaging behaviours, aggression, fear and stress in farm animals. Appl. Anim. Behav. Sci. 103, 205–214.

Rudine, A.C., Sutherland, M.A., Hulbert, L., Morrow, J.L., McGlone, J.J., 2007. Diverse production system and social status effects on pig immunity and behavior. Livest. Sci. 111, 86–95.

Rushen, J., 1987. A difference in weight reduces fighting when unacquainted newly weaned pigs first meet. Can. J. Anim. Sci. 67, 951–960.

Salak-Johnson, J.L., DeDecker, A.E., Horsman, M.J., Rodriguez-Zas, S.L., 2012. Space allowance for gestating sows in pens: behaviour and immunity. J. Anim. Sci. 90, 3232–3242.

Samarakone, T.S., Gonyou, H.W., 2009. Domestic pigs alter their social strategy in response to social group size. Appl. Anim. Behav. Sci. 121, 8–15.

Sapkota, A., Marchant-Forde, J.N., Richert, B.T., Lay Jr., D.C., 2016. Including dietary fiber and resistant starch to increase satiety and reduce aggression in gestating sows. J. Anim. Sci. 94, 2117–2127.

Schaefer, A.L., Salomons, M.O., Tong, A.K.W., Sather, A.P., Lepage, P., 1990. The effect of environmental enrichment on aggression in newly weaned pigs. Appl. Anim. Behav. Sci. 27, 41–52.

Schmolke, S.A., Li, Y.Z., Gonyou, H.W., 2004. Effects of group size on social behaviour following regrouping of growing-finishing pigs. Appl. Anim. Behav. Sci. 88, 27–38.

Schneider, J.D., Tokach, M.D., Dritz, S.S., Nelssen, J.L., DeRouchey, J.M., Goodband, R.D., 2007. Effects of feeding schedule on body condition, aggressiveness, and reproductive failure in group-housed sows. J. Anim. Sci. 85, 3462–3469.

Scollo, A., Gottardo, F., Contiero, B., Edwards, S.A., 2014. Does stocking density modify affective state in pigs as assessed by cognitive bias, behavioural and physiological parameters? Appl. Anim. Behav. Sci. 153, 26–35.

Scott, J.P., Fredericson, E., 1951. The causes of fighting in mice and rats. Physiol. Zool. 24, 273–309.

Scott, K., Taylor, L., Gill, B.P., Edwards, S.A., 2007. Influence of different types of environmental enrichment on the behaviour of finishing pigs in two different housing systems: 2. Ratio of pigs to enrichment. Appl. Anim. Behav. Sci. 105, 51–58.

Séguin, M.J., Barney, D., Widowski, T.M., 2006. Assessment of a group-housing system for gestating sows: effects of space allowance and pen size on the incidence of superficial skin lesions, changes in body condition, and farrowing performance. J. Swine Health Prod. 14, 89–96.

Šilerová, J., Špinka, M., Šárová, R., Algers, B., 2010. Playing and fighting by piglets around weaning on farms, employing indiviudal or group housing of lactating sows. Appl. Anim. Behav. Sci. 124, 83–89.

Skok, J., Prevolnik, M., Urek, T., Mesarec, N., Škorjanc, D., 2014. Behavioural patterns established during suckling reappear when piglets are forced to form a new dominance hierarchy. Appl. Anim. Behav. Sci. 161, 42–50.

Spicer, H.M., Aherne, F.X., 1987. The effects of group size/stocking density on weanling pig performance and behaviour. Appl. Anim. Behav. Sci. 19, 89–98.

Spoolder, H.A.M., Burbidge, J.A., Edwards, S.A., Simmins, P.H., Lawrence, A.L., 1995. Provision of straw as a foraging substrate reduces the development of excessive chain and bar manipulation in food restricted sows. Appl. Anim. Behav. Sci. 43, 249–262.

Spoolder, H.A.M., Burbridge, J.A., Edwards, S.A., Lawrence, A.B., Simmins, P.H., 1997. Effect of food level on performance and behaviour of sows in a dynamic group-housing systems with electronic feeding. Anim. Sci. 65, 473–482.

Spoolder, H.A.M., Geudeke, M.J., Van der Peet-Schwering, C.M.C., Soede, N.M., 2009. Group housing of sows in early pregnancy: a review of success and risk factors. Livest. Sci. 125, 1–14.

Stewart, C.L., O'Connell, N.E., Boyle, L., 2008. Influence of access to straw provided in racks on the welfare of sows in large dynamic groups. Appl. Anim. Behav. Sci. 112, 235–247.

Stolba, A., Woodgush, D.G.M., 1989. The behavior of pigs in a semi-natural environment. Anim. Prod. 48, 419–425.

Stookey, J.M., Gonyou, H.W., 1994. The effects of regrouping on behavioural and production parameters in finishing swine. J. Anim. Sci. 72, 2804–2811.

Strawford, M.L., Li, Y.Z., Gonyou, H.W., 2008. The effect of management strategies and parity on the behaviour and physiology of gestating sows housed in an electronic sow feeding system. Can. J. Anim. Sci. 88, 559–567.

Stukenborg, A., Traulsen, I., Puppe, B., Presuhn, U., Krieter, J., 2011. Agonistic behaviour after mixing in pigs under commercial farm conditions. Appl. Anim. Behav. Sci. 129, 28–35.

Stukenborg, A., Traulsen, I., Stamer, E., Puppe, B., Presuhn, U., Krieter, J., 2012. Heritabilities of agonistic behavioural traits in pigs and their relationships within and between different age groups. Livest. Sci. 149, 25–32.

Taylor, I.A., Barnett, J.L., Cronin, G.M., 1997. Optimum group size for pigs. In: Proceedings for the 5th International Symposium American Society of Agricultural Engineers, St. Joseph, Michigan, USA, pp. 965–971.

Tönepöhl, B., Appel, A.K., Voß, B., von Borstel, U., Gauly, M., 2013. Interaction between sows' aggressiveness post mixing and skin lesions recorded several weeks later. Appl. Anim. Behav. Sci. 144, 108–115. Available from: http://dx.doi.org/10.1016/j.applanim.2013.01.004.

Telkänranta, H., Edwards, S.A., 2017. Lifetime consequences of the early physical and social environment of piglets. In: Špinka, M. (Ed.), Advances in Pig Welfare. Woodhead Publishing, Duxford, UK.

Tuchscherer, M., Puppe, B., Tuchscherer, A., Kanitz, E., 1998. Effects of social status after mixing on immune, metabolic, and endocrine responses in pigs. Physiol. Behav. 64, 353–360.

Turner, S.P., Edwards, S.A., 2004. Housing immature domestic pigs in large social groups: implications for social organisation in a herarchial society. Appl. Anim. Behav. Sci. 87, 239–253.

Turner, S.P., Camerlink, I., Baxter, E.M., D'Eath, R.B., Desire, S., Roehe, R., 2017. Breeding for pig welfare; opportunities and challenges. In: Špinka, M. (Ed.), Advances in Pig Welfare. Woodhead Publishing, Duxford, UK.

Turner, S.P., Farnworth, M.J., White, I.M.S., Brotherstone, S., Mendl, M., Knap, P., Mendl, M., Knap, P., Penny, P., Lawrence, A.B., 2006a. The accumulation of skin lesions and their use as a predictor of individual aggressiveness in pigs. Appl. Anim. Behav. Sci. 96, 245–259.

Turner, S.P., White, I.M.S., Brotherstone, S., Farnworth, M.J., Knap, P.W., Penny, P., Mendl, M., Lawrence, A.B., 2006b. Heritability of post-mixing aggressiveness in grower-stage pigs and its relationship with production traits. Anim. Sci. 82, 615–620.

Turner, S.P., Roehe, R., D'Eath, R.B., Ison, S.H., Farish, M., Jack, M.C., Lundeheim, N., Rydhmer, L., Lawrence, A.B., 2009. Genetic validation of postmixing skin injuries in pigs as an indicator of aggressiveness and the relationship with injuries under more stable social conditions. J. Anim. Sci. 87, 3076–3082.

Turner, S.P., Roehe, R., Mekkawy, W., Farnworth, M.J., Knap, P.W., Lawrence, A.B., 2008. Bayesian analysis of genetic associations of skin lesions and behavioural traits to identify genetic components of individual aggressiveness in pigs. Behav. Genet. 38, 67–75.

Valros, A., 2017. Tail biting. In: Špinka, M. (Ed.), Advances in Pig Welfare. Woodhead Publishing, Duxford, UK.

van der Weerd, H.A., Docking, C.M., Day, J.E.L., Breuer, K., Edwards, S.A., 2006. Effects of species-relevant environmental enrichment on the behaviour and productivity of finishing pigs. Appl. Anim. Behav. Sci. 99, 230–247.

van Putten, G., van de Burgwal, J.A., 1990. Vulva biting in group-housed sows—preliminary report. Appl. Anim. Behav. Sci. 26, 181–186.

van Putten, G., Buré, R.G., 1997. Preparing gilts for group housing by increasing their social skills. Appl. Anim. Behav. Sci. 54, 173–183.

Verdon, M., Hansen, C.F., Rault, J.-L., Jongman, E., Hansen, L.U., Plush, K., Hemsworth, P.H., 2015a. Effects of group housing on sow welfare: a review. J. Anim. Sci. 93, 1999–2017.

Verdon, M., Morrison, R.S., Hemsworth, P.H., 2015b. Short and long-term repeatability of individual sow aggressiveness. Anim. Prod. Sci. 55, 1512 (abstract).

Verdon, M., Morrison, R.S., Rice, M., Hemsworth, P.H., 2016a. Individual variation in sow aggressive behaviour and its relationship with sow welfare. J. Anim. Sci. 94, 1203–1214.

Verdon, M., Morrison, R.S., Hemsworth, P.H., 2016b. Rearing piglets in multi-litter group lactation systems: effects on piglet aggression and injuries post-weaning. Appl. Anim. Behav. Sci. 183, 35–41.

Verdon, M., Morrison, R.S., Rice, M., Butler, K., Hemsworth, P.H., 2017. The short-term behavioural response of sows to a social stimulus is related to sow aggressiveness in groups. Behav. Process. 140, 216–225.

Verlarde, A., 2007. Agonistic behaviour. In: Verlarde, A., Reers, R. (Eds.), On Farm Monitoring of Pig Welfare. Wageningen Academic Press, Wageningen, The Netherlands, pp. 53–56.

Wang, L.H., Li, Y.Z., 2016. Effect of continuous access to feeding stalls during mixing on behaviour, welfare and performance of group-housed gestating sows in different social ranks. Can. J. Anim. Sci. 96, 386–396.

Weng, R.C., Edwards, S.A., English, P.R., 1998. Behaviour, social interactions and lesion scores of group-housed sows in relation to floor space allowance. Appl. Anim. Behav. Sci. 59, 307–316.

Whittaker, X., Edwards, S.A., Spoolder, H.A.M., Lawrence, A.B., Corning, S., 1999. Effects of straw bedding and high fibre diets on the behaviour of floor fed group-housed sows. Appl. Anim. Behav. Sci. 63, 25–39.

Wolter, B.F., Ellis, M., Curtis, S.E., Parr, E.N., Webel, D.M., 2000. Group size and floor-space allowance can affect weanling-pig performance. J. Anim. Sci. 78, 2062–2067.

Wolter, B.F., Ellis, M., DeDecker, J.M., Curtis, S.E., Hollis, G.R., Shanks, R.D., et al., 2002. Effects of double stocking and weighing frequency on pig performance in wean-to-finish production systems. J. Anim. Sci. 80, 1442–1450.

Worobec, E.K., Duncan, I.J.H., Widowski, T.M., 1999. The effects of weaning at 7, 14 and 28 days on piglet behaviour. Appl. Anim. Behav. Sci. 62, 173–182.

Zanella, A.J., Brunner, P., Unshelm, J., Mendl, M.T., Broom, D.M., 1998. The relationship between housing and social rank on cortisol, beta-endorphin and dynorphin (1-13) secretion in sows. Appl. Anim. Behav. Sci. 59, 1–10.

Zayan, R., 1990. The effect of social recognition upon aggression and corticosteroid response in triads of piglets. In: Zayan, R., Dantzer, R. (Eds.), Social Stress in Domestic Animals. Kluwer, Dordrecht, The Netherlands, pp. 157–202.

Zegarra, N., Hemsworth, P. H. and Verdon, M., 2017. Floor feeding over multiple drops does not increase feeding opportunities for submissive sows. In: Proceedings of the 51st Congress of the International Society for Applied Ethology. Aarhus, Denmark, 7–10 August. 177 pp. (abstract).

Zhao, Y., Flowers, W.L., Saraiva, A., Yeum, K.J., Kim, S.W., 2013. Effect of social ranks and gestation housing systems on oxidative stress status, reproductive performance, and immune status of sows. J. Anim. Sci. 91, 5848–5858.

Transport of pigs to slaughter and associated handling

9

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9.1 Introduction

Transportation is one of the common pig production practices that pigs may be subjected to more than once in their lifetime, i.e. when piglets are transferred from the nursery to the grow-to-finish facilities, and when market-weight pigs are shipped for slaughter. However, based on the proportion of pigs that are are found dead on the truck (dead-on-arrival or DOA) or that are nonambulatory on arrival at the slaughter plant (Ritter et al., 2009), and the behavioural and physiological response (heart rate, body temperature and blood parameters), transportation, including loading and unloading, has been reported to be one of the most stressful events in a pigs' life (Bench et al., 2008; Schwartzkopf-Genswein et al., 2012; McGlone et al., 2014b). The stress of being transported can be so great in affecting the physiological condition of pigs at the time of slaughter, resulting in meat quality defects (Schwartzkopf-Genswein et al., 2012).

Over the years, transport research primarily addressed animal welfare, regulatory and pork industry economic concerns related to the loss of animals in transit (Ritter et al., 2009). A review of 23 field trials conducted in the USA between 2000 and 2007 reported that of all pigs marketed, 0.25% died during transport and an additional 0.44% were nonambulatory upon arrival to the plant, costing the US swine industry approximately US$46 million annually (Ritter et al., 2009). A further US transport survey of 16,000 journeys (2.7 million pigs) over 12 months reported a total transport loss (dead and nonambulatory pigs) of 0.46%, made up of 0.19% DOA and 0.27% nonambulatory pigs (Sutherland et al., 2009). In Canada, a CAN $4 million loss was reported as a consequence of death (13,000 deaths or 0.08%) during transport and reduced carcass value (30%) related to a high percentage (0.44%) of pigs becoming nonambulatory during transport (Schwartzkopf-Genswein et al., 2012). Economic losses also result from monetary penalties (CAN $ 6,000 fine) for transporters who have 3–4 dead pigs in a single truck load (CFIA, 2016). In Europe, Averós et al. (2008) monitored 739 journeys to 37 slaughter plants in 5 different countries (Spain, Portugal, France, Germany and Italy) and reported that the percentages of dead and injured pigs during unloading were 0.11% and 0.36%, respectively.

The objective of this chapter is to provide an overview of current findings of research conducted in Europe, North and South America aiming at studying the

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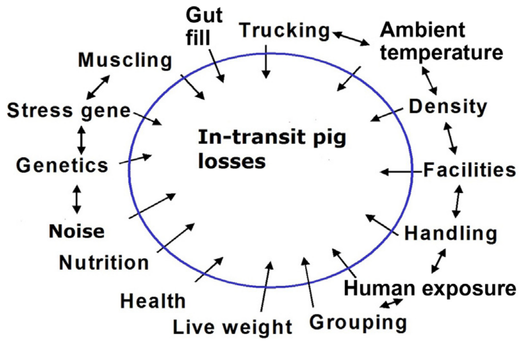

Figure 9.1 Contributing factors leading to in-transit animal losses.
Adapted from NPB (2014).

effects of the on-farm conditions. We look at the raising system and previous handling experience, feed withdrawal, handling techniques, loading facilities design, and of the travel conditions (i.e. vehicle design, transport time and distance, loading density, driving conditions and handling at unloading) on pigs' response to the stress of transport and associated handling preslaughter as assessed by total animal losses (Fig. 9.1), physiological and behavioural responses, and carcass and meat quality variation. Poor handling and transport conditions may, in fact, result in carcass and meat losses due to severe skin lesions and weight losses, and abnormal postmortem muscle acidification (Schwartzkopf-Genswein et al., 2012).

9.2 On-farm and loading

The response of pigs to transport stress varies based on the farm of origin (Dalla Costa et al., 2007a; Dewey et al., 2009). An epidemiological study run in Canada reported 0.17% DOA and 0.27% nonambulatory pigs on arrival at the plant and identified the major source of animal losses variation as being the farm (25%) followed by the transporter and the packer (16% each; Sunstrum et al., 2006; Dewey et al., 2009). The effect of the farm of origin on animal losses and stress response reported in this study may be attributed to differences in the preparation of pigs for transport (e.g. feed withdrawal), barn design and in the handling of pigs as they are moved out of the barn and loaded onto the truck (Stewart et al., 2008; Correa et al., 2010; Correa, 2011).

9.2.1 Preparation for transport

9.2.1.1 Raising system

Raising conditions at the farm are considered a major source of variation in the easiness of handling pigs commonly observed between batches of pigs preslaughter (Grandin, 1993; Grandin and Vogel, 2011).

During the fattening period, pigs are usually kept in the same pen under intensive, barren or with little environmental enrichment housing conditions, resulting in pigs showing a high degree of reactivity to novel stimuli, less developed social behaviour or increased fearfulness (De Jonge et al., 1996; Olsson et al., 1999; O'Connell et al., 2005; Rocha et al., 2016). In contrast, research has showed that pigs raised in an enriched environment, in terms of larger pens and straw bedding, appear to be easier to handle at loading, are less reactive to transport stress (lower salivary cortisol levels) and fight less when mixed with unfamiliar conspecifics than those raised under barren housing conditions (De Jong et al., 2000; Klont et al., 2001; Terlouw, 2005; Barton-Gade, 2008; Terlouw et al., 2009; Tönepöhl et al., 2012). Recently, Rocha et al. (2016) reported a greater reluctance to move at loading and greater percentage of turning back and slips at unloading in pigs raised at conventional farms (confined housing on partially slatted floor and 0.74 m^2/pig floor space allowance) compared with pigs raised through animal welfare improved raising system (minimum space allowance of 0.85 m^2/pig, presence of bedding, quiet handling using trained handlers and frequent management operations). It is well known, in fact, that pigs that are used to handling and exercise on a farm display a calmer behaviour (Grandin, 1998) and are more fit, resulting in better handling and reduced workload for stockmen (Geverink et al., 1998). Due to the greater physical fitness, a lower percentage of panting pigs on arrival at the abattoir was observed in batches of pigs originating from animal welfare-improved farms compared to conventional ones (Rocha et al., 2016).

9.2.1.2 Preparatory handling experience

Ried and Mills (1962) suggested that animals can be trained to accept some irregularities in management and thus reduce violent reactions to novelty. Training pigs to be driven through the alley at the farm during the late finishing period (from last 3 weeks to last day) appears to increase easiness of handling at loading reducing moving time by 60 seconds (Abbott et al., 1997), to improve the cardiovascular response to loading stress (Goumon et al., 2013a) and to reduce the proportion of pigs exhibiting open-mouth breathing and skin discolouration, both indicators of physical stress, during loading, and total transport losses (Stewart et al., 2008) compared with pigs that had not been previously moved. Also, the previous exposure to a loading ramp once a day for one week prior to slaughter resulted in lower pigs' heart rate during handling and shorter time to complete a handing course compared to naïve pigs (Lewis et al., 2008). However, it is apparent that this training better works when pigs have the experience of being pushed up and down ramps instead of having voluntary access to a ramp (Goumon et al., 2013a).

9.2.1.3 Feed withdrawal

While water must be always available during the marketing process (CEC, 2005; National Farm Animal Care Council, 2014), feed withdrawal is a recommended practice for on-farm preparation of pigs before slaughter in order to prevent animal losses or travel sicknesss during transport (Bradshaw et al., 1996b; SCAHAW, 2002; Averós et al., 2008; National Farm Animal Care Council, 2014), to reduce carcass contamination due to lower risk of gut contents spillage during carcass evisceration and to improve pork quality (Faucitano et al., 2010). Death in unfasted pigs results from the pressure of the full stomach on the vena cava, which reduces its diameter and decreases the blood flow efficiency (Warriss, 1994). However, when compared to unfasted pigs, fasted groups of pigs (18 hours prior to loading) appear to be less easy to handle at loading, as showed by the greater proportion of pigs going backward, making 180 degree turns and vocalising (Dalla Costa et al., 2016). These behaviours may result from increased frustration, fatigue and excitement caused by hunger (Arnone and Dantzer, 1980; Lewis, 1999; Lewis and McGlone, 2008; Edwards et al., 2010).

A feed withdrawal time (last feed to slaughter) between 16 and 24 hours appears to be an acceptable compromise between the welfare of animals during handling and transport and food safety and quality (Eikelenboom et al., 1991; Guàrdia et al., 1996; Stewart et al., 2008; Faucitano et al., 2010). However, despite these potential advantages, under specific commercial conditions, i.e. marketing of pigs by weight (split-marketing; see later in the chapter), fasting is sometimes only applied from the departure from the farm to the abattoir (Aalhus et al., 1992; Viau and Champagne, 1998). The reason for this misapplication is the producers' concern about the risk of slower growth rate of pigs remaining in the pen and the lack of a shipping room where the heaviest pigs can be transferred ahead of loading time and feed can be withdrawn at the same time (Viau and Champagne, 1998). If, on the one hand, this practice may still prevent the risk of full stomachs at slaughter, provided the 16–24 hours fasting time is respected by imposing longer lairage time at the abattoir, on the other hand, it may reduce the welfare of pigs during transport and in lairage (Guàrdia et al., 1996; Stewart et al., 2008). Indeed, the imposition of longer lairage time should be avoided as it increases the fighting rate, in terms of number and duration of fights, between mixed groups of pigs due to hunger-related irritability and excitement (Fernandez et al., 1995; Brown et al., 1999), eventually resulting in greater risk of bruised carcasses and DFD (dark, firm, dry) pork (Guàrdia et al., 2009; Dalla Costa et al., 2016).

9.2.2 Loading facilities and handling

Loading pigs onto the truck is considered the most critical stage of the transport period as shown by the increase in pig heart rate (up to 160 heart beats; Correa et al., 2013) and by the increase of stress indicators (salivary cortisol and blood lactate) levels compared to the values observed for a pig at rest, with the effects of loading stress lasting until slaughter and eventually affecting meat quality (Bradshaw et al., 1996b; Correa et al., 2010; Edwards et al., 2010). The stress associated with loading procedure results from a combination of different factors, such as group splitting in the finishing pen, the design of the loading facility (either ramp or dock), group size and handling system. These factors also affect the management and control of loading time. Loading time is an important factor in the profitability of producer and trucker operations, because the faster the truck is loaded, the more trips a trucker can make during the day and the more time the producer can devote to other farm tasks. Research has shown that longer loading times due to poor facility design (alley, ramp or dock) and large group size may result in higher risk of carcass bruises (Guàrdia et al., 2009). Shorter loading times are beneficial for farmer and trucker time saving, but should not result from rough handling (e.g. electric prodding; Correa et al., 2010) which may increase the risk of non-ambulatory pigs on arrival at the slaughter plant, greater skin lesions and PSE (pale, soft, exudative) pork production (Guàrdia et al., 2004; Correa et al., 2010).

9.2.2.1 Group splitting in the finishing pen

The most stressful task a market pig must cope with during transport to slaughter is the initial departure from the finishing pen as it involves a close human–animal interaction and its separation from the group (Geverink et al., 1998). Group splitting at the time of loading is applied to handle small groups of pigs through the alleys up to the truck gate in both all-out and split-marketing strategies. All-out marketing strategy consists of marketing all pigs from a pen in one single shipment. However, the application of this practice may increase aggressiveness near the end of the finishing stage due to increasing reduction of space allowance for the heavier pigs (Conte et al., 2012) and may result in animal losses (DOA and downers) during transport due to inadequate provision of space in the truck for pigs of different liveweight (Ritter et al., 2007). In contrast, the split-marketing strategy, which is very common in France, Spain and North America (Chevillon, 2001a; Scroggs et al., 2002; A. Velarde, IRTA, Spain, personal communication), implies the removal of the heaviest 25%–50% of pigs from a pen to market 1–2 weeks earlier than the other pen-mates. Its advantage is the reduction of production costs due to shorter finishing phase and the opportunity to ship batches with a more uniform market weight to the abattoir (Scroggs et al., 2002; Conte et al., 2012). Furthermore, the removal of the heaviest animals increases their feed efficiency and growth rate of pigs due to increased floor and feeder space (Scroggs et al., 2002; DeDecker et al., 2005). However, this practice may also alter their social environment leading to fighting aiming at establishing a new social hierarchy (Scroggs et al., 2002; Conte et al., 2012). When compared with groups of pigs split in the pen and moved directly to the loading dock, Johnson et al. (2010) and Gesing et al. (2010) reported reduced physical signs of stress (open mouth breathing and skin discolouration) during loading in pigs pre-sorted from large pens (192 and 292 pigs/pen, respectively) prior to loading. Furthermore, Johnson et al. (2010) found a 66% decrease in total losses on arrival at the abattoir in pre-sorted groups. However, it is unclear if this improvement is due to raising pigs in large pens and/or the management practice of pre-sorting market weight pigs prior to loading (Johnson et al., 2013). Raising pigs in large pens, in fact, may allow them to be more fit for handling and transport as they had more room to exercise during the grow-finish period and may reduce the number of unfamiliar pigs that are mixed during transportation (Johnson et al., 2013), resulting in fewer transport losses (Brumsted, 2004). Hayne et al. (2009)

reported that when compared with small groups (16–18 pigs/pen), loading batches of pigs (4 pigs per batch) from large groups (250 pigs/pen) tended to take shorter time (~ 26 seconds).

9.2.2.2 Distance to the truck gate

In large swine units, animals are often required to walk long distances to get to the loading area. According to Ritter et al. (2008a), at US farms the average distance over which pigs are moved to reach the loading area is commonly greater than 100 m. This situation may result in muscle fatigue during loading and transportation as showed by the increased frequency of open-mouth breathing and skin discolouration (signs of acute stress) at loading and at unloading in pigs moved over a long distance (up to 91 m) compared with those moved over a short one (<24 m) to reach the loading area (Ritter et al., 2007, 2008a). Similarly, greater postloading lactate concentrations have been found in pigs moved for 46 versus 15 m to the loading area (Edwards et al., 2011). Therefore, the distance to the loading area should be minimised as much as possible by using, for example, shipping rooms that are usually located near the barn exit and to which pigs are moved to a minimum of 2–4 hours before loading (Chevillon, 2001a). Besides being recommended for biosecurity and feed withdrawal control (Chevillon, 2001b; Faucitano et al., 2010; Brandt and Aaslyng, 2015), this practice proved to reduce the time to load 100 pigs from 50 to 20 minutes, resulting in lower number of fatigued pigs at loading (Gesing et al., 2010) and a 25% decrease in transport mortality rate (Chevillon, 2001a).

9.2.2.3 Loading group size and alley design

The correct choice of the size of the group of pigs to move forward guarantees the smooth flow of pigs through the alleys and ramps, without stressing the animal and hence reducing the workload for handlers. Moving pigs in groups of 4 to 6 pigs resulted in a lower increase in heart rate and a faster loading time due to less round-turns, and in a reduced number of DOA (0.19% vs 0.56%) or nonambulatory pigs (0.36% vs 0.7%) on arrival at the plant compared to larger groups (≥7 pigs; Lewis and McGlone, 2007; Berry et al., 2009). However, moving pigs in a group size larger than the width of the farm alley, loading dock or ramp is a common practice at loading as it is mistakenly considered effective to speed up the handling procedure. According to Grandin et al. (2002), alley width is an important factor to consider in the recommendations regarding group size. Moving small groups (3–6 pigs) appears to ease handling through narrow alleys (up to 1.2 m; Chevillon, 2001b; Grandin et al., 2002).

Furthermore, to ensure a smooth flow of pigs through the alley, 90° corners should be avoided as they can be perceived as a dead end by animals (Grandin, 1978; Warriss et al., 1992; Chevillon, 1998). Goumon et al. (2013c) also showed that the presence of a 30 degrees corner led to a better movement of animals compared with 60 degrees and 90 degrees angles, creating a smoother path to the ramp.

9.2.2.4 Ramp design

The main factors contributing to the highest peaks in heart rate of pigs at loading are most likely climbing and descending a ramp. Pigs' heart rate, loading time, frequency of turn backs and balking have been reported to increase as the ramp slope increases from 0 degree to 45 degrees (van Putten and Elshof, 1978; Warriss et al., 1991; Garcia and McGlone, 2015), reflecting a greater physical and psychological challenging experience as the slope increases (van Putten and Elshof, 1978; Grandin, 1997; Goumon et al., 2013c). Dalla Costa et al. (2007b) also reported an increased number of handling-type bruises when using a ramp steeper than 20 degrees to load the upper deck of a double-decked truck. It has been also showed that steep ramps (up to 26 degrees) are also challenging, in terms of increased heart rate and work load, for the handler (Goumon et al., 2013c).

To reduce slips, falls and vocalisation in pigs at loading in winter and summer, different bedding types (feed, sand, wood shavings and hay) can be used on ramps. Garcia and McGlone (2015) reported that all bedding types, except for hay, reduced handling time through the ramp when compared to no bedding in winter.

The use of a staircase may be an alternative to reduce the slope or length of the ramp and also reduces slipperiness when the ramp is wet (due to presence of faeces and urine; Grandin, 2000), which may cause stress and injuries to animals due to slipping and falling. To this end, 8 cm high and 30 cm long steps on the ramp are recommended for loading market pigs (Grandin, 2008).

At the truck gate, a step resulting from the height difference between the dock floor or ramp and the truck deck is often observed in commercial conditions (Fig. 9.2). A step higher than 15 cm at this point should be avoided as it makes pigs

Figure 9.2 The presence of a step or gap between ramp and deck floor at loading or unloading makes pigs reluctant to move forward resulting in difficult handling (L. Faucitano, AAFC, Canada).

reluctant to move forward resulting in difficult handling (SCAHAW, 2002). The presence of a 20 cm initial step at the bottom of a loading ramp at loading and unloading has been reported to be both challenging for the handler, as showed by his greater heart rate, increased number of slaps, touches and vocalization required and longer loading time, and for pigs as they are observed to back-up and baulk in front of it (Weschenfelder et al., 2012, 2013; Goumon et al., 2013c).

Given the difficult handling through ramps, alternative systems, such as the loading gantry, have been developed and tested for their efficiency and effects on pig welfare at loading (Berry et al., 2012). The loading gantry consists of an aluminium covered chute with two dual pivoting extension systems that allow for proper positioning to both the barn and trailer. The chute slope is 7 degrees to the bottom deck and 18 degrees to the upper deck of the trailer. A cushioned bumper dock system is present to completely eliminate gaps between the barn exit and the loading gantry. When compared to a regular (19 degrees slope) loading ramp, the use of the loading gantry improved the loading process as indicated by the reduction of electric prod use and produced fewer overlaps, slips, falls and balking occurrences, and vocalisations in pigs. The reduced loading stress eventually resulted in lower transport losses (Berry et al., 2012).

9.2.2.5 Moving tools

Under commercial conditions, pigs are usually moved using plastic sorting paddles and boards, electric prods or flags. These tools do not have the same efficiency and the same effects on the behaviour and physiology of pigs during handling. Some authors describe the use of electric prods as being as stressful as the loading procedure (Becker et al., 1985) and more aversive than 90% CO_2 inhalation (Jongman et al., 2000). Their use is not recommended because they reduce easiness of handling (Brundige et al., 1998; McGlone et al., 2004) and may result in greater incidence of nonambulatory pigs (Benjamin et al., 2001; Correa et al., 2010). Furthermore, they elicit a negative physiological and behavioural response, in terms of higher incidence of backing-up, round turns, slipping, falling, jumping, jamming and high-pitched vocalisation (Rabaste et al., 2007; Correa et al., 2010; Edwards et al., 2010; Dokmanovic et al., 2014), and greater heart rates and blood cortisol and lactate concentrations (Brundige et al., 1998; Hemsworth et al., 2002; Bertol et al., 2005; Correa et al., 2010; Edwards et al., 2010). For all these reasons, regulations and codes of practice recommend to limit, if not to avoid, the use of electric prods for pig handling at any stage preslaughter (EC, 1993; SCAHAW, 2002; National Farm Animal Care Council, 2014). In respect of these requirements, many abattoirs in Europe and North America have banned electric prods from their list of handling tools (Gentry et al., 2008; Correa, 2011). However, this tool still appears largely used on farm and on the truck to speed up the procedure of loading and reduce the workload of handlers through the ramps (Faucitano, 2001). Griot and Chevillon (1997) reported that 9 out 10 French drivers own an electric prod and 75% of them use it at loading, while in Canada it has been observed that 50%–95% of producers and truck drivers regularly use electric prods to move their pigs (Murray, 2001; Correa, 2011). As Grandin (2002) points out, electric prods should be used only as a last resort, and only when a fit animal refuses to move forward. However, even in this extreme situation, abusive use of this handling tool should not be permitted. Research has showed that the electric prod should not be used more than twice and for less than ≤ 1 second each on a pig during handling (Ritter et al., 2008b). The abusive use of the electric prod may reflect the handler's lack of experience or training (Faucitano, 2001; Correa et al., 2010) or the poor farm and/or truck design (Driessen and Geers, 2001; Correa, 2011; Torrey et al., 2013b).

Flags, paddles and plastic boards can be considered good alternatives to the use of electric prods. McGlone et al. (2004) compared the efficiency and effects of these tools, and concluded that the sorting board and the flag were the most efficient devices for moving pigs because they appear as solid and blocking walls. However, their efficiency may be impaired if the animal can see the edges of the devices, in which case pigs may attempt to exploit them to try to escape. These authors also reported that plastic paddles were less aversive than electrical prods, but their use resulted in more vocalisations and a lower handling efficiency compared to the use of plastic boards. In addition, they do not allow the handlers to reach the animals at the front of the line that are impeding the other pigs from moving forward, all resulting in pig jamming along the way and handling delays. When comparing the use of plastic boards combined with paddle or electric prod along the alley and the loading ramp, Correa et al. (2010) concluded that from an animal welfare, carcass bruising and blood splashes in meat standpoint, the paddle should replace the electric prod.

9.2.2.6 Mixing unfamiliar groups of pigs

As it exacerbates aggressiveness, physical fatigue, carcass lesions and DFD pork, mixing pigs from different pens at the farm and on the truck is not a recommended practice (Warriss, 1996; EFSA, 2011; National Farm Animal Care Council, 2014). However, under commercial conditions, pigs are normally mixed at the farm (shipping room) and/or on the truck aiming at obtaining groups of uniform weight and filling the truck compartments to their maximum capacity (Faucitano, 2001). To limit fighting rate and duration, it is recommended to provide the shipping pen with divisions/barriers to create hiding/protection areas (McGlone and Curtis, 1985) and adjust the stocking density according to the wait time before loading (from 0.45 m^2/pig for <30 minutes wait to 0.65 m^2/pig for periods longer than 3 hours; SCAHAW, 2002). The installation of mobile dividing gates on the truck deck is also a practical solution to eliminate mixing as, besides keeping the groups separated, it helps to adjust compartment space to suitable group size (Faucitano and Geverink, 2008). On the truck fighting between mixed groups of pigs is more frequently observed during stops than while the vehicle is moving (Warriss, 1996).

9.3 Transport and unloading

Transportation is a multicomponent phenomenon, consisting of the effects of multiple factors that greatly impact the welfare of pigs. After the departure from the farm, these factors include vehicle design, ambient conditions (temperature, humidity, vibrations and noise), travel duration, space allowance, driving conditions and handling at unloading (Weeks, 2008; Schwartzkopf-Genswein et al., 2012; Brandt and Aaslyng, 2015).

9.3.1 Vehicle design

In a study where a large fixed body truck was compared to a small towed twin-axle trailer, Randall et al. (1996) concluded that vehicle type accounts more for the comfort of pigs during transit than other transport factors, such as animal location in the vehicle.

The vehicle type for pig transportation to slaughter can vary widely, from small single deck trucks to large three-deck punch-hole trailers, either ‘pot-belly’ or straight/flat-deck models (Fig. 9.3A—C). These latter trailer models are common in North America as they allow transport large loads of pigs (more than 200) on three decks (10 compartments) in one journey and for long distances.

Vehicle design features that may have an impact of the welfare of pigs during transport include the loading system (ramps or hydraulic device), microclimate control and floor type.

Figure 9.3 (A)Brazilian single-decked truck (photo courtesy O.A. Dalla Costa, Embrapa, Brazil); (B) North American pot-belly and (C) flat-deck trailers (L. Faucitano, AAFC, Canada); (D) European truck with hydraulic tail-gate lift system (courtesy A. Velarde, IRTA, Spain).

9.3.1.1 Within truck loading system

The use of fixed decks and ramps is known to result in higher risk of DOA (Barton-Gade et al., 2007) and PSE pork (Guàrdia et al., 2004). North American pot-belly trailers are an example of vehicles featuring multiple (up to 5) and steep (up to 40° slope) internal ramps and 180° turns to load and unload the top and bottom fixed decks (Fig. 9.4A, B). Comparative studies showed that the presence of these ramps may result in lower easiness of handling during loading and unloading increasing the use of electric prods (up to 32%) and extending the time of moving pigs inside the vehicle (Ritter et al., 2008a; Torrey et al., 2013a,b; Weschenfelder et al., 2013). These observations have been used to explain the greater proportion of DOA and fatigued pigs on arrival at the abattoir, and greater exsanguination blood cortisol concentration when this trailer type is used instead of other vehicle types, equipped with hydraulic decks, such as a double-decked truck or a flat-deck trailer (Ritter et al., 2008a; Sutherland et al., 2009; Kephart et al., 2010; Weschenfelder et al., 2012; Correa et al., 2013, 2014). Weschenfelder et al. (2013) also found higher stress response (based on exsanguination blood CK concentration) and pork water exudation in the ham and loin muscles from Piétrain Hal^{Nn} crossbred pigs being transported over a short distance (40 km) using a pot-belly trailer compared with a flat-deck trailer (Weschenfelder et al., 2013).

The hydraulic tail-lift system is often installed on small (100 pigs load) European trucks (Fig. 9.3D). However, when compared with the use of moderately sloped ramps (16 degrees−18 degrees slope), the tailgate system did not result in a different physiological response as assessed by heart rate, body temperature and blood cortisol concentration (Brown et al., 2005; Nanni Costa et al., 1999, 2002), but appears to make pigs more reluctant to enter the truck (Brown et al., 2005). The pigs' perception of the lift as a novel experience may explain the lack of difference

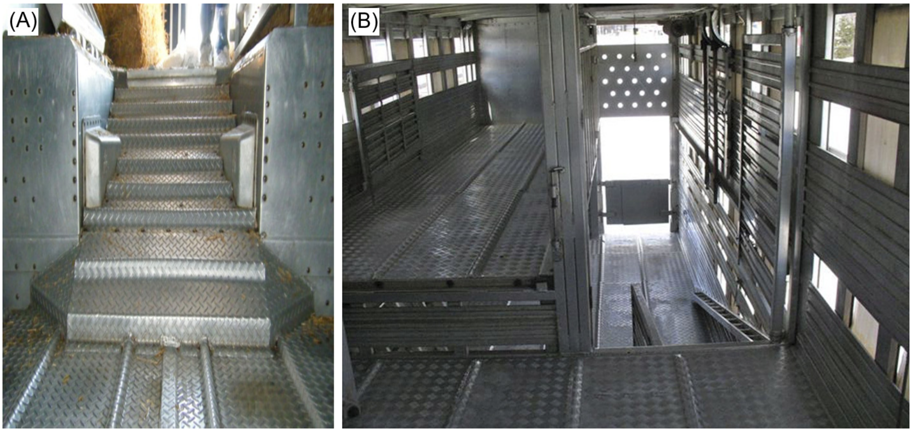

Figure 9.4 (A) Internal ramp and (B) turns to get to bottom and upper compartments, respectively, in the pot-belly trailer (S. Goumon, Institute of Animal Science, Czech Republic; L. Faucitano, AAFC, Canada).

in the physiological and behavioural results between the two loading systems (McGlone et al., 2014b).

9.3.1.2 Animal location in the vehicle

Animal location, i.e. deck and compartment position in the vehicle, during trasportation has an impact on its welfare and meat quality (Bench et al., 2008). European studies reported that pigs transported on the lower deck of trucks had higher body temperature and blood cortisol levels and showed a higher degree of dehydration and skin damage score (Lambooij et al., 1985; Lambooij and Engel, 1991; Barton-Gade et al., 1996), all resulting in a greater incidence of PSE or DFD pork. These effects may be respectively caused by poor ventilation or pigs' physical effort to keep their standing position in order to cope with the high level of vibrations at this location (Guise and Penny, 1992; Barton-Gade et al., 1996; Randall et al., 1996; Zanella and Duran, 2000). Within the pot-belly trailer, a higher propotion of pale or exudative pork was reported in pigs transported in the top and/or bottom decks compared with the middle deck (Correa et al., 2013; Newman et al., 2014).

Within the deck of European and Brazilian trucks, greater body weight losses and a higher incidence of deaths in transit have been reported in the front compartment (Christensen and Barton-Gade, 1999; Dalla Costa et al., 2007b). In European trucks, higher temperatures and serum cortisol and CK concentrations, and a trend for higher blood albumin concentrations and osmolality at exsanguination were reported in pigs transported in the top front compartments compared with rear ones (Warriss et al., 2006). Other European studies reported poor meat quality (PSE or DFD) and higher exsanguination blood lactate levels in pigs transported in the front and rear compartments compared to pigs travelling in the middle pens (Guise and Penny, 1989; Barton-Gade et al., 1996). The results of these studies may indicate that pigs located in these truck positions were exposed to more physical and psychological stress resulting from poor ventilation, vibration and loading order.

Transport trials using the pot-belly trailer showed that the front and rear top, and bottom rear compartments are more critical for pigs than other compartments as showed by the increased gastrointestinal tract temperature after loading and during transport in summer (Conte et al., 2015), higher heart rate after loading and longer unloading time associated with more slips (Goumon et al., 2013b; Torrey et al., 2013b), and paler loins in summer (Correa et al., 2013). Higher pH, darker colour and lower drip loss values, indicative of DFD pork, were reported in the ham muscles of pigs located in the front middle compartment ('bottom-nose'; Correa et al., 2014). The risk for DFD pork production from this vehicle location may be aggravated by longer transportation (18 hours) and winter conditions (Scheeren et al., 2014). The physical effort needed to negotiate the steep internal ramps to reach these compartments and the different microclimate conditions across compartments may explain these results.

9.3.1.3 Microclimate control inside the vehicle

It has been reported that as the internal trailer temperature increases, the number of pigs that are DOA also increases. The vehicle internal temperature increases by 0.99°C and 0.11°C as the environmental temperature and relative humidity increase by 1°C and 1%, respectively (Dewey et al., 2009). This temperature increase is greater in pot-belly trailer than in flat-deck trailers either while stationary or moving (Ritter et al., 2008a; Weschenfelder et al., 2012). This difference in internal temperatures may be explained by the reduced ventilation in the pot-belly trailer compared with the flat-deck trailer due to different perforation patterns on the sides openings between the two trailer models, with the punch-type pattern openings of the pot-belly trailer allowing lower air flow compared with the slatted openings of the flat-deck trailer (Weschenfelder et al., 2012). Chevillon et al. (2004) recommends openings of 40 cm in hot weather condition to ensure a good ventilation (300 m^3/hour of air flow per pig) inside the truck.

Within the pot-belly trailer, higher temperatures have been recorded in the front compartments of the middle and bottom deck, while the top compartments presented lower temperatures (Brown et al., 2011). The higher and lower temperatures have been explained by the reduced ventilation and poor insulation, respectively (Brown et al., 2011).

Stops during the journey are a source of pig mortality during transport in vehicles without mechanical ventilation due to an increase in temperature. Temperatures up to approximately 30.2°C have been reported inside a stationary pot-belly trailer, with the bottom front compartments being up to 10°C warmer than the external ambient temperature during Canadian commercial transports (Brown et al., 2011; Weschenfelder et al., 2012, 2013; Fox et al., 2014). As suggested by Brown et al. (2011), in the summer, pigs kept in a stationary pot-belly trailer should be cooled by water sprinkling or fan ventilation or the two systems combined.

The application of 5 minutes water sprinkling at the departure from the farm after loading and 5 minutes before unloading at the slaughter plant when ambient temperature exceeded 23°C showed to decrease pigs' gastrointestinal tract temperature upon arrival at the plant and drinking behaviour in lairage (Fox et al., 2014). Whereas, when applied starting from 20°C ambient temperature, water sprinkling reduced exsanguination blood lactate concentration, indicator of fatigue, and improved meat quality (higher initial pH and lower drip loss in the loin muscle) in pigs transported in the middle front and rear compartments compared with those located in these compartments in the unsprinkled trailer (Nannoni et al., 2014). However, an increase in relative humidity (up to 7.5%) has been observed in a sprinkled trailer, which may prevent from an efficient evaporative cooling (Fox et al., 2014). To prevent this problem, fan-assisted ventilation can be suggested as an alternative cooling system, although its effects on the welfare of pigs in the vehicle are unclear, ranging from positive (Nielsen, 1982) to none (Warriss et al., 2006). The use of forced ventilation (starting from 20°C) combined with a misting system (starting from 25°C) has been suggested to improve animal welfare in hot

Figure 9.5 Use of fan-misting bank during wait time before unloading in the slaughter plant yard (L. Faucitano, AAFC, Canada).

weather conditions as it helps remove the excessive humidity from the interior of the sprinkled truck reducing pigs' body temperature by increasing evaporative cooling (Christensen et al., 2007). The application of forced ventilation for 30 minutes before unloading using external fan banks (Fig. 9.5) in combination with 10 minutes water misting appears to improve thermal comfort (lower gastrointestinal tract temperature) and to reduce dehydration (lower blood haematocrit level) in pigs kept in a stationary truck during the wait before unloading (Pereira et al., 2016).

To control the vehicle internal environment and maintain pigs' thermo-neutral zone in winter, the ventilation openings should be partially or fully closed, reducing the air flow to one third (113 m^3/hour of air flow per pig; Chevillon et al., 2004). To this end, vehicles must be fitted with boarding, i.e. proportion of side walls of the vehicle closed by inserting boards or plugs, to block out most of the cold and keep the pig heat in the vehicle (Fig. 9.6). According to the Transport Quality Assurance (TQA) handbook guidelines the side vent opening should go from 10% (or 90% boarding) at temperatures below −12°C to 100% (no boarding or all side vents open) starting from 9.4°C (NPB, 2008). The use of low boarding level (0%–30%) at temperatures below 5°C may produce the highest transport losses, while the boarding level (0 to >61%) appears to have little impact on animal losses at temperatures higher than 5°C (McGlone et al., 2014a).

The insulation of the coolest parts (e.g. top deck compartments; Brown et al., 2011) of the truck can be also beneficial to pigs' thermal comfort in winter. For

Figure 9.6 In winter, vehicles must be fitted with boarding to block out most of the cold and keep the pig heat in the vehicle (L. Faucitano, AAFC, Canada).

example, research showed that adding a 5 cm layer Styrofoam insulation to the ceiling of the top compartments increases the temperature of these compartments by 10°C during cold weather transport (−20°C; Gonyou and Brown, 2012).

Floor type is also important for the thermal comfort of pigs during transport. Lightweight rubber is the most recommended material for the vehicle deck floor because of its good insulating, along with antiskid and antinoise, properties (Christensen and Barton-Gade, 1996), resulting in 1.5% lower incidence of PSE pork when compared with aluminium and iron flooring (Guàrdia et al., 2004).

According to the EU legislation, dry bedding is mandatory in the truck to improve comfort of pigs around resting (CEC, 2005). Schutte et al. (1996) showed that straw or deep, dry shavings at temperatures below 10°C helped maintain the pig body temperature and normal heart rate. However, the efficiency of bedding in providing thermal comfort in pigs appears to depend on the floor material and quantity of bedding (number of bales). Goumon et al. (2013b) anecdotally reported that pigs transported in winter (−14.3 ± 1.7°C, ranging from −28.8 to 1.9°C) presented frostbite on their body likely caused by an insufficient dry wood shavings bedding, which did not protect the pig body from the contact with the frozen aluminium floor surface of the trailer. According to McGlone et al. (2014b), no more than 6 bales of bedding/vehicle may be required in winter, but this level should be increased in harsh winter conditions, while no more than 3 bales of bedding are recommended in warm conditions. However, if, on one hand, more bedding would increase the thermal comfort of pigs, on the other hand, it may result in difficult footing and handling problems (Kephart et al., 2014).

9.3.2 Transport conditions

9.3.2.1 Season

Extreme environmental temperature during transit is generally considered one of the greatest contributors to transport losses (Clark, 1979; Haley et al., 2008a,b; Sutherland et al., 2009). Transport deaths have been reported to increase at temperatures above 20°C (Sutherland et al., 2009) and to double from 0.15% to 0.30% when the outside temperature is >35°C (Grandin, 1994). The percentage of pigs showing open-mouth breathing on arrival at the plant also increases at ambient temperatures greater than 17°C (Kephart et al., 2010). Haley et al. (2008b) and Correa et al. (2013) reported greater animal losses in summer, with the highest deaths being recorded during the month of August (0.40%) when the maximum ambient temperature was 33.6°C (Haley et al., 2008b). In a more recent Italian large scale survey of 24,000 journeys over 5 years, the greatest frequency of deaths was reported in July with a risk ratio of 1.22 (Vitali et al., 2014). However, seasonal effects on total transport losses do not always correspond with increases in environmental temperature, but also with low temperatures. Clark (1979) and Guàrdia et al. (1996) reported greater mortality losses in winter and Sutherland et al. (2009) found increased rates of nonambulatory pigs on arrival at the plant at ambient temperatures ≤5°C, with the highest peaks being recorded during the late autumn and early winter months (Rademacher and Davies, 2005; Ellis and Ritter, 2006). Canadian transport studies, in fact, reported more in-transit animal welfare problems in winter than in summer, with pigs hauled in winter being more difficult to handle through pot-belly internal ramps at loading and unloading (Torrey et al., 2013a,b), standing more during transport (Goumon et al., 2013b; Torrey et al., 2013a,b), presenting higher heart rates during transport and at unloading (Goumon et al., 2013b; Correa et al., 2014), and having greater exsanguination blood CK and lactate concentrations (Correa et al., 2014) and more carcass bruises (Scheeren et al., 2014).

9.3.2.2 Travel distance and time

The relationship between journey length and transport stress does not appear to be linear. Greater DOA are generally reported for transport distances lower than 100 km (Gosálvez et al., 2006; Barton Gade et al., 2007). Haley et al. (2008b) found that for each 50 km increase in distance, DOA can be expected to decrease 0.81 times and finally reported a decreased risk of in-transit death losses with distances over 134 km. Whereas in European studies, DOA increased from 0.06% to 0.34% when transport distance increased from <50 to >300 km (Vecerek et al., 2006; Malena et al., 2007). According to Marchant-Forde and Marchant-Forde (2009), the effects of transport time more than transport distance should be considered as the total time pigs spend in the truck, including loading, transit and unloading, are better correlated with animal losses on arrival at the slaughter plant (Ritter er al., 2006). In US transport surveys, mortality increased with journeys from 0.5 to 4 hours and decreased after 4 hours, along with the percentage of nonambulatory pigs (Rademacher and Davies, 2005; Sutherland et al., 2009; McGlone et al., 2014b). Higher concentrations of cortisol and lactate in exsanguination blood, resulting in higher risk for PSE pork production, were also reported after short journeys (from 15 minutes to <2 hours; Fortin, 2002; Pérez et al., 2002). Whereas in a German epidemiological study, both short and long transport time (<1 and >8 hours, respectively) contributed to increase DOA (Werner et al., 2007).

Overall, it is thus apparent that shorter transports (<1 hour) may be more detrimental than longer ones as pigs must be given the time to recover from the stress of loading and to acclimate to the stress of transport (Tarrant, 1989; Stephens and Perry, 1990; Bradshaw et al., 1996a,b; Sutherland et al., 2009). Barton-Gade and Christensen (1998) observed, in fact, that pigs increasingly began to sit and lie down after 20–30 minutes of transport. Hence, when provided more time, pigs may eventually adapt to the novel truck environment and travel conditions, but only if the transport conditions, i.e. space allowance, vehicle design, and within truck ambient temperature and humidity, are good (Bench et al., 2008). Based on the results of comparative studies between a pot-belly trailer and flat-deck trailer used for short or long distance transport (45 minutes and 7 hours, respectively), Weschenfelder et al. (2013) concluded that the pot-belly trailer is not suitable for short transportation as pigs have no time to recover from the stress of loading, which is greater for this vehicle type (see earlier in this chapter), resulting in fatigued pigs at slaughter. Whereas in the long distance transportation study, the effects of vehicle design were masked by the good travel conditions, i.e. appropriate space allowance, allowing pigs to accommodate and recover from the stress of loading (Weschenfelder et al., 2012).

However, there is also evidence that pigs transported for long durations may be more exposed to fatigue, muscle glycogen stores exhaustion and dehydration, as showed by the higher blood glucose, lactate and haematocrit levels at slaughter and greater risk for DFD pork (Brown et al., 1999; Fortin, 2002; Leheska et al., 2003; Mota-Rojas et al., 2006; Becerril-Herrera et al., 2010). However, these results are more likely due to the additive effects of fasting duration, mixing, ambient conditions and pig genetics than to transport time or distance per se (Salmi et al., 2012; Goumon et al., 2013b; Scheeren et al., 2014; Brandt and Aaslyng, 2015). For example, Vitali et al. (2014) reported increased DOA risk ratio for journeys longer than 2 hours in summer. Whereas Canadian transport studies showed that pigs transported for 18 hours in winter showed higher gastrointestinal tract temperature and heart rate than those hauled for the same time in summer (Goumon et al., 2013b). Furthermore, in a companion study (Scheeren et al., 2014), the effects of season and travel duration on pork quality were aggravated by the compartment location in the pot-belly trailer, with winter longer transport time (18 hours) resulting in pork with DFD characteristics in pigs located in the top and rear bottom compartments.

9.3.2.3 Rest periods, food and water

With the objective to let pigs recover from the effects of dehydration, hunger and general fatigue suffered during long distance transportation, a resting period on the

Table 9.1 Comparison of regulations and recommendations for different regions on providing rest, water and food during pig transport

	Type	Time without rest, water and/or feed	Specifics of food, water and rest
Canada[a,b]	Regulations and Guidelines	Maximum of 36 h (proposed reduction to 28 h).	Pigs must be fed prior to loading for trips over 12 h. Minimum of 5 hours for feed, water, rest between two transport periods.
USA[c]	Regulations and Guidelines	Maximum of 28 h.	Minimum of 5 hours for feed, water, rest between two transport periods.
European Union[d]	Regulations	No more than 8 h except for suitable vehicle and in this case, 24 h (with continuous access to water). Journey times may be extended by 2 h, depending on proximity to final destination.	After 24 hours, animals must be unloaded, fed and watered for at least 24 hours.
Brazil[e]	Regulations	Maximum of 12 h (for all species).	After 12 hours, water must be provided on the truck.
Australia[f]	Regulations and Guidelines	Maximum of 24 h (but journey time can be extended to 72 h provided that feed and water are provided in-transit within every 24 h).	After 24 hours, pigs are to be rested for 12 hours.
China[g]	Guidelines	Maximum of 8 h.	No requirement

[a]CARC (2001)
[b]Government of Canada (2016)
[c]GPO (1994)
[d]CEC (2005)
[e]Brasil (1934)
[f]Australian Animal Welfare Standards and Guidelines (2012)
[g]Standards of China Association for Standardisation (2014)
Adapted from Bench et al., (2008).

truck or at control posts is recommended or mandated (Bench et al., 2008; www.controlpost.eu). Table 9.1 provides an overview of international standards concerning pig transport journey duration, including the provision of feed, water and rest periods during transit. Besides the lack of consensus on the length of rest periods, another consideration is the stress of unloading and loading animals at a control post and mixing them in a novel environment (Bench et al., 2008). However, this negative effect on the welfare of pigs stopping at control post and rest can be minimised by applying good handling practices and space allowance in the rest pen as well as using well designed ramp, corridors and pens (www.controlpost.eu). Feeding and watering pigs on the truck can avoid the stress of handling in and off the truck, and mixing in the control post pens (Lambooij, 2000; Chevillon et al., 2003). However, to ensure an appropriate feed and water intake, the truck should be stationary (Lambooij et al., 1985; Chevillon et al., 2003).

9.3.2.4 Loading density

Market pigs can experience higher mortality, have more injuries and produce lower meat quality if the space allowed in the vehicle during transport is not appropriate (Bench et al., 2008).

At a space allowance lower than 0.42 m^2/100 kg pig, which is the minimum legal allowance in the EU (EU 95/29/EC), mortality rates and the percentage of non-ambulatory pigs on arrival at the plant were found to increase (Riches et al., 1996; Warriss et al., 1998; Ritter et al., 2006), likely due to the greater physical stress (as showed by increased blood CK levels and skin damage score; Guise and Penny, 1989; Barton-Gade and Christensen, 1998; Warriss et al., 1998) caused by continual disturbance of recumbent animals by those seeking a place to rest and difficulty of standing pigs to keep balance during vehicle accelerations, breaking and turns (Lambooij and Engel, 1991). However, US transport trials showed that transport losses are minimised when market weight pigs (average 131 kg) were provided with transport floor spaces of 0.35–0.39 m^2/100 kg pig compared to 0.30–0.34 m^2/100 kg pig (total losses: 0.13–0.98% vs 1.9–2.9%) during a 3 hours journey (Ritter et al., 2007). However, increasing the space availability from 0.37 to 0.50 m^2/100 kg pig may also result in about an 11% increase in the risk of producing DFD meat due to lower fatigue-related muscle glycogen exhaustion (Guàrdia et al., 2005). Providing more space may indeed cause a greater physical stress, with pigs being at a greater risk of being thrown around and got struck due to unexpected and sudden movements of the truck, or fighting due to their greater freedom to move around in the truck (Barton-Gade and Christensen, 1998; Guàrdia et al., 2005).

Research showed that the application of the EU requirement for loading densities should be adjusted according to travel time. Pilcher et al. (2011) showed that reducing floor space (0.40–0.49 vs 0.52 m^2/100 kg) appears to increase the incidence of pigs showing open-mouth breathing on arrival at the plant after short transport (<1 hours) compared with longer journeys (3 hours). However, Guàrdia et al. (2004) reported that the application of higher loading densities (0.25 vs 0.5 m^2/100 kg) in short journeys (1 hour) resulted in decreased incidence of PSE pork and concluded that, in order to prevent this quality defect, the EU recommended space allowance of 0.425 m^2/100 kg may be only appropriate for journeys longer than 3 hours. These results may be explained by the fact that giving more space (0.42 and 0.50 vs 0.35 m^2/100 kg) does not necessarily result in more pigs lying down, especially during the first 2 hours of transport (Lambooij et al., 1985; Barton-Gade and Christensen, 1998), but it causes more disturbance and aggression due to animals being able to move around, loss of balance and greater risk of being thrown around, getting stuck and bruised when the vehicle negotiates bends or poor road surfaces (Warriss, 1995; Barton-Gade and Christensen, 1998). The provision of greater space allowance is beneficial for pigs transported long distance. Lambooij and Engel (1991) investigated the effect of transporting pigs over long distances (25 hours) and found that when pigs were provided more space (0.59 vs 0.39 m^2/100 kg), they laid down earlier in transport with the number of lying pigs remaining high compared with lower space allowances of 0.39 or 0.47 m^2/pig. More recently, Gerritzen et al. (2013) reported a better adaptability of pigs to a long journey (550 km) when transported at higher space allowance (0.56 vs 0.42 m^2/100 kg) as showed by higher resting behaviour and reduced body temperature and heart rate.

9.3.2.5 Driving conditions

Amongst the stressors pigs are challenged with during transportation, driving conditions may be associated with the fact that pigs do not lie down on short journeys (Grandin, 2002). It has been demonstrated that pigs stand more on rough journeys (Bradshaw et al., 1996c; Randall et al., 1995) and wild driving (Peeters et al., 2008) probably because of the level of vibrations, which together with noise and sudden movements (braking and cornering), are aversive for pigs (Peeters et al., 2008; Perremans et al., 1998). Standing seems to alleviate motion sickness, however may result in a higher level of injuries and bruises (Barton-Gade and Christensen, 1998). There is evidence that rough journeys resulted in lower pH at 45 minutes with higher incidence of PSE meat (Hoffman and Fisher, 2010).

9.3.2.6 Reception at the abattoir

Based on its impact on animal welfare of livestock at this stage, the timeliness of arrival of the truck is a core criterion evaluated by numerical scoring within slaughterhouse audit protocols (AMI, 2012). The primary recommendation is to begin unloading of animals within 0.5 hours of arrival at the slaughterhouse and complete it within an hour to avoid heat and humidity rise inside the stationary truck and its negative consequences on animal welfare and meat quality of pigs (AMI, 2012). However, in commercial conditions, the waiting time to unload a truck after its arrival at the slaughterhouse is very variable ranging from 0 minutes to 4 hours (Aalhus et al., 1992; Ritter et al., 2006; Sutherland et al., 2009). As previously described in this chapter, in passively ventilated vehicles, stops are detrimental for the quality of the internal ambient conditions. Weschenfelder et al. (2012) reported that, even after only 10 minutes wait before unloading at mild ambient temperatures (8°C), temperatures in some compartments of the transport truck can be up to 6°C warmer than the external temperature. The microclimate change inside the truck can explain the correlation between time waiting in the yard and the risk of death and/or nonambulatory pigs at unloading reported in several studies (Ritter et al., 2006; Haley et al., 2008a,b). Sutherland et al. (2009) showed that keeping pigs waiting in the vehicle without mechanical ventilation up to 4 hours at the abattoir prior to unloading at temperatures above 20°C increased mortality to 0.28%. According to Haley et al. (2008a,b), the risk of pigs dying can increase by 2.2 times at every 0.5 hours increase in the waiting time. Driessen and Geers (2001) also reported the greatest incidence of PSE pork after 30 minutes wait when at 23°C ambient temperature or after 53 minutes wait at 11°C (70% and 45%, respectively). The presence of heat-stressed (or panting) pigs at unloading is a major risk factor for PSE pork production (van de Perre et al., 2010). Thermoregulation of pigs during lairage period is discussed in the following chapter (Velarde and Dalmau, Chapter 10: Slaughter of pigs).

A strict coordination of truck arrivals with the predicted number of pigs in lairage, lairage capacity and speed of operation as well as a number of unloading docks allowing more than one truck to unload at the same time may help shorten waiting times in abattoirs (Faucitano and Pedernera, 2016).

Similarly to loading, at unloading, special attention should be paid to ramp slopes (<15 degrees −20 degrees), lighting and noises (Grandin, 1996, 2002) and floor gaps due to height difference between the truck deck and the unloading ramp or dock (SCAHAW, 2002). The noise level produced during unloading (up to 78 dB) was the major factor influencing the muscle pH drop rate (pH at 30 minutes postmortem) at Belgian abattoirs (van de Perre et al., 2010).

To avoid jamming and panic in the unloading group, the truck should be emptied gradually by unloading pigs by compartment rather than by deck and in small groups using paddles or boards only (Faucitano and Geverink, 2008). The use of electrical prods makes handling at unloading more difficult as it increases the number of mounting, slipping and about turning (Rabaste et al., 2007).

9.4 Conclusions and future trends

The quality of the design of the loading facilities and of the handling system plays a key role in determining the effects of the farm on pig response to preslaughter stress and on meat quality. To reduce the load time and the workload of loading crews, it is recommended that farms use shipping rooms, move pigs in batches suited to the alley and ramp size and minimise, if not eliminate, the use of electric prods. The implementation of animal welfare programme, including these improvements, joined with economic incentives, helped reduce the proportion of animal losses from 0.41% to 0.08% and of condemned carcasses from 0.13% to 0.03% (Correa, 2011). However, with regard to moving tools, more research is needed to develop a low-stress handling tool to assist loading crews in loading and moving pigs in challenging areas, such as the transition area between the barn and the loading area and loading ramps.

The use of truck models featuring hydraulic ramps or decks also proved to help reduce the workload of handlers and improve the welfare of pigs during transport.

Amongst current international regulations and guidelines on loading density and rest time during long distance transportation, a consensus exists on the following key points: (1) animals should be partitioned in order to minimise injury during transport; (2) loading density should be reduced during warmer weather; (3) animals have feed and water requirements during transport. However, there is no firm agreement on how much loading densities should change according to ambient conditions, pig liveweight and travel time, and how long they should travel without feed and water and how long they should be kept in the control post to be fed, watered and rested after long distance transportation. The discrepancy in these standards is basically due to the lack of science-based recommendations meeting the animal welfare requirements and trucking companies' economics.

Research on swine transportation is relatively decreasing in Europe and increasing in North and South America, where it will be likely focusing on the: (1) improvement of truck design by studying the air flow patterns and vibration rate; (2) validation of insulation and cooling systems in the truck under colder and hotter ambient conditions where temperature control becomes more critical and physiological heat maintenance and dissipation in pigs becomes less effective; (3) identification of adequate loading densities under warm and cold conditions and according to pig slaughter weight, and travel time and rest time during long distance transportation.

Abbreviations

CK creatine kinase
DFD dark, firm, dry
DOA dead-on-arrival
PSE pale, soft, exudative.

References

Aalhus J.L., Murray A.C., Jones S.D.M., Tong, A.K.W., 1992. Environmental conditions for swine during marketing for slaughter – a national review. Technical Bulletin 1992-6E, Research Branch, Agriculture and Agri-Food Canada.

Abbott, T.A., Hunter, E.J., Guise, H.J., Penny, R.H.C., 1997. The effect of experience of handling on pigs' willingness to move. Appl. Anim. Behav. Sci. 54, 371–375.

AMI, 2012. Recommended Animal Handling Guidelines and Audit Guide: a Systematic Approach to Animal Welfare. AMI Foundation, Washington, DC, 108p.

Arnone, M., Dantzer, R., 1980. Does frustration induce aggression in pigs? Appl. Anim. Ethol. 6, 351–362.

Australian Animal Welfare Standards and Guidelines, 2012. Land transport of livestock. Australian Government, Dept. Agriculture, Fisheries and Forestry. Available at: <http://www.animalwelfarestandards.net.au/files/2015/12/Land-transport-of-livestock-Standards-and-Guidelines-Version-1.-1-21-September-2012.pdf>.

Averós, X., Knowles, T.G., Brown, S.N., Warriss, P.D., Gosálvez, L.F., 2008. Factors affecting the mortality of pigs being transported to slaughter. Vet. Rec. 163, 386–390.

Barton-Gade, P., 2008. Effect of rearing system and mixing at loading on transport and lairage behaviour and meat quality: comparison of free range and conventionally raised pigs. Animal. 2, 1238–1246.
Barton-Gade, P., Christensen, L., 1998. Effect of different loading densities during transport on welfare and meat quality in Danish slaughter pigs. Meat Sci. 48, 237–247.
Barton-Gade, P., Christensen, L., Brown, S.N., Warriss, P.D., 1996. Effect of tier and ventilation during transport on blood parameters and meat quality in slaughter pigs. Proceedings of the EU-Seminar: New information on welfare and meat quality of pigs as related to handling, transport and lairage conditions, Landbauforschung Völkenrode, vol. 166, pp. 101–116.
Barton-Gade, P., Christensen, L., Baltzer, M., Petersen, J.V., 2007. Causes of pre- slaughter mortality in Danish slaughter pigs with special emphasis on transport. Anim. Welf. 16, 459–470.
Becerril-Herrera, M.M., Alonso-Spilsbury, M., Trujillo-Ortega, M.E., Guerrero-Legarreta, I., Ramirez-Necoechea, R., Roldan-Santiago, P., Perez-Sato, M., Soni-Guillermo, E., Mota-Rojas, D., 2010. Changes in blood constituents of swine transported for 8 or 16 h to an abattoir. Meat Sci. 86, 945–948.
Becker, B.A., Nienaber, J.A., Christenson, R.K., Manak, R.C., DeShazer, J.A., Hahn, G.L., 1985. Peripheral concentrations of cortisol as an indicator of stress in the pig. Am. J. Vet. Res. 46, 1034–1038.
Bench, C., Schaefer, A.L., Faucitano, L., 2008. The welfare of pigs during transport. In: Faucitano, L., Schaefer, A.L. (Eds.), The Welfare of Pigs - from Birth to Slaughter. Wageningen, Academic Publishing, Wageningen, The Netherlands, pp. 161–195.
Benjamin, M.E., Gonyou, H.W., Ivers, D.J., Richardson, L.F., Jones, D.J., Wagner, J.R., Seneriz, R., Anderson, D.B., 2001. Effect of animal handling method on the incidence of stress response in market swine in a model system. J. Anim. Sci. 79, 279.
Berry, N.L., Ritter, M.J., Brunton, E., Stremsterfer, W., Hoag, B., Wolfe, J., Fitzgerald, N., Porth, M., Delaney, D., Weldon, T., 2009. Effects of moving market weights pigs in different group sizes during loading on stress responses and transportation losses at the packing plant. In: Proceedings of the Midwest American Society of Animal Science, Des Moines, IA, p. 5.
Berry, N.L., Johnson, A.K., Hill, J., Lonergan, S., Karriker, L.A., Stalder, K.J., 2012. Loading gantry versus traditional chute for the finisher pig: Effect on welfare at the time of loading and performance measures and transport losses at the harvest facility. J. Anim. Sci. 90, 4028–4036.
Bertol, T.M., Ellis, M., Ritter, M.J., McKeith, F.K., 2005. Effect of feed withdrawal and handling intensity on longissimus muscle glycolytic potential and blood measurements in slaughter weight pigs. J. Anim. Sci. 83, 1536–1542.
Bradshaw, R.H., Hall, S.J.G., Broom, D.M., 1996a. Behavioural and cortisol response of pigs and sheep during transport. Vet. Rec. 138, 233–234.
Bradshaw, R.H., Parrott, R.F., Forsling, M.L., Goode, J.A., Lloyd, D.M., Rodway, R.G., Broom, D.M., 1996b. Stress and travel sickness in pigs: effects of road transport on plasma concentrations of cortisol, beta-endorphin and lysine vasopressin. Anim. Sci. 63, 507–516.
Bradshaw, R.H., Parrott, R.F., Forsling, M.L., Goode, J.A., Lloyd, D.M., Rodway, R.G., Broom, D.M., 1996c. Behavioral and hormonal responses of pigs during transport: effect of mixing and duration of journey. Anim. Sci. 62, 547–554.
Brandt, P., Aaslyng, M.D., 2015. Welfare measurements of finishing pigs on the day of slaughter: a review. Meat Sci. 103, 13–23.

Brasil, 1934. Legislação Tempo Máximo de Transporte. Decreto-Lei nº. 24.645 de 10 de julho de 1934, Artigo 3º - Item XVII, p. 2.

Brown, J., Samarakone, T.S., Crowe, T., Bergeron, R., Widowski, T., Correa, J.A., Faucitano, L., Torrey, S., Gonyou, H.W., 2011. Temperature and humidity conditions in trucks transporting pigs in two seasons in eastern and western Canada. Trans. ASABE. 54, 1−8.

Brown, S.N., Knowles, T.G., Edwards, J.E., Warriss, P.D., 1999. Relationship between food deprivation before transport and aggression in pigs held in lairage before slaughter. Vet. Rec. 145, 630−634.

Brown, S.N., Knowles, T.G., Wilkins, L.J., Chadd, S.A., Warriss, P.D., 2005. The response of pigs being loaded or unloaded onto commercial animal transporters using three systems. Vet. J. 170, 91−100.

Brumsted, M., 2004. Automatically sorted, large pen finish barns reduce death loss during transportation to market. In: Proceedings of the American Association of Swine Veterinarians, Des Moines, IA, p. 47.

Brundige, L., Oleas, T., Doumit, M., Zanella, A.J., 1998. Loading techniques and their effect on behavioural and physiological responses of market weight pigs. J. Anim. Sci. 76, 99.

Canadian Food Inspection Agency, 2016. Administrative monetary penalties. Available at: <http://www.inspection.gc.ca/about-the-cfia/accountability/complianceandenforcement/amps/eng/1324319195211/1324319534243>.

CARC, 2001. Recommended code of practice for the care and handling of farm animals - Transportation. Canadian Agri-Food Research Council.

CEC, 2005. Regulation No 1/2005 relative to the protection of animals during transportation. The Council of the European Communities. December 22, 2004. Amends Directives 64/432/EEC and 93/119/EC and Regulation (EC) No. 1255/97.

Chevillon, P., 1998. Taux de mortalité lors du transportation et bien-être du porc. Techni-Porc. 21, 13−18.

Chevillon, P., 2001a. Bien-être des porcs lors des opérations de pré-abattage et d'anesthésie. Techni-Porc. 24, 15−22.

Chevillon, P., 2001b. Pig welfare during pre-slaughter and stunning. Proceedings of the 1st Int. Virtual Conf. on Pork Quality. Embrapa, Concordia, Brazil, pp. 145−158.

Chevillon, P., Frotin, P., Rousseau, P., Kerisit, R., 2003. Incidence sur le bien-être des porcs de la densité de chargement et du protocole d'alimentation lors d'un transport des porcs de 36 heures incluant 9 heures d'arrêt. Journées de la Recherche Porcine en France. 35, 179−186.

Chevillon, P., Frotin, P., Rousseau, P., 2004. Hauteurs des compartiments et ventilation lors d'un transport des moins de 8 heures. Techni-Porc. 27, 1−3.

Christensen L., Barton-Gade P., 1996. Design of experimental vehicle for transport of pigs and some preliminary results of environmental measurements. Proceedings of the EU Seminar: New information on welfare and meat quality of pigs as related to handling, transport and lairage conditions, Landbauforschung Völkenrode, vol. 166, pp. 47−68.

Christensen, L., Barton-Gade, P., 1999. Temperature profile in double-decker transporters and some consequences for pig welfare during transport, Farm Animal Welfare - Who Writes the Rules? 23. Occasional Publication of the British Society of Animal Science, pp. 125−128.

Christensen, L., Blaabjerg, L., Hartung, J., 2007. Investigation of pig transports for more than 8 hours in cold and warm weather conditions and of the requirements for ventilation during the transport. Report 24, Project no: DS02770. Danish Meat Research Institute, Roskilde, Denmark.

Clark, E.G., 1979. A post mortem survey of transport deaths in Saskatchewan market hogs. Western Hog J. 1, 34–36.

Conte, S., Lawlor, P.G., O'Connell, N., Boyle, L.A., 2012. Effect of split marketing on the welfare, performance, and carcass traits of finishing pigs. J. Anim. Sci. 90, 373–380.

Conte, S., Faucitano, L., Bergeron, R., Torrey, S., Gonyou, H.W., Crowe, T., Widowski, T. M., 2015. Effects of season, truck type and location within truck on gastrointestinal tract temperature of market-weight pigs during transport. J. Anim. Sci. 93, 5840–5848.

Correa, J.A., 2011. Effect of farm handling and transport on physiological response, losses and meat quality of commercial pigs. Adv. Pork Prod. 22, 249–256.

Correa, J.A., Torrey, S., Devillers, N., Laforest, J.P., Gonyou, H.W., Faucitano, L., 2010. Effects of different moving devices at loading on stress response and meat quality in pigs. J. Anim. Sci. 88, 4086–4093.

Correa, J.A., Gonyou, H.W., Torrey, S., Widowski, T., Bergeron, R., Crowe, T.G., Laforest, J.P., Faucitano, L., 2013. Welfare and carcass and meat quality of pigs being transported for 2 hours using two vehicle types during two seasons of the year. Can. J. Anim. Sci. 93, 43–55.

Correa, J.A., Gonyou, H.W., Torrey, S., Widowski, T., Bergeron, R., Crowe, T.G., Laforest, J.P., Faucitano, L., 2014. Welfare of pigs being transported for long distance using a pot-belly trailer during winter and summer. Animals. 4, 200–213.

Dalla Costa, F.A., Devillers, N., Paranhos da Costa, M.J.R., Faucitano, L., 2016. Effects of applying preslaughter feed withdrawal at the abattoir on behaviour, blood parameters and meat quality in pigs. Meat Sci. 119, 89–94.

Dalla Costa, O.A., Faucitano, L., Coldebella, A., Ludke, J.V., Peloso, J.V., Dalla Roza, D., Paranhos da Costa, M.J.R., 2007a. Effects of the season of the year, truck type and location on truck on skin bruises and meat quality in pigs. Livest. Sci. 107, 29–36.

Dalla Costa, O.A., Ludke, J.V., Paranhos da Costa, M.J.R., Faucitano, L., Peloso, J.V., dalla Roza, D., 2007b. Modelo de carroceria e seu impacto sobre o bem-estar e a qualidade da carne dos suínos. Ciência Rural. 37, 1418–1422.

DeDecker, J.M., Ellis, M., Wolter, B.F., Corrigan, B.P., Curtis, S.E., Parr, E.N., Webel, D. M., 2005. Effects of proportion of pigs removed from a group and subsequent floor space on growth performance of finishing pigs. J. Anim. Sci. 83, 449–454.

De Jong, I.C., Prelle, I.T., Van De Burgwal, J.A., Lambooij, E., Korte, S.M., Blokhuis, H.J., Koolhaas, J.M., 2000. Effects of rearing conditions on behavioural and physiological responses of pigs to preslaughter handling and mixing at transport. Can. J. Anim. Sci. 80, 451–458.

De Jonge, F.H., Bokkers, E.A.M., Schouten, W.G.P., Helmond, F.A., 1996. Rearing piglets in a barren environment: developmental aspects of social stress in pigs. Physiol. Behav. 60, 389–396.

Dewey, C., Haley, C., Widowski, T., Poljak, Z., Friendship, R., 2009. Factors associated with in-transit losses of fattening pigs. Anim. Welf. 18, 355–361.

Dokmanović, M., Velarde, A., Tomović, V., Glamočlija, N., Marković, R., Janjić, J., Baltić, M.Z., 2014. The effects of lairage time and handling procedure prior to slaughter on stress and meat quality parameters in pigs. Meat Sci. 98, 220–226.

Driessen, B., Geers, R., 2001. Stress during transportation and quality of pork - a European view. In: Proceedings of the 1st International Virtual Conference on Pork Quality. Embrapa, Concordia, Brazil, pp. 39–51.

EC, 1993. Council Directive (93/119/CEE) of 22 December 1993 on the protection of animals at the time of slaughter or killing. Available at: <http://eur-lex.europa.eu/legal-content/EN/TXT/?uri = celex:31993L0119> (accessed 02/05/2016).

Edwards, L.N., Grandin, T.A., Engle, T.E., Porter, S.P., Ritter, M.J., Sosnicki, A., Anderson, D.B., 2010. Use of exsanguination blood lactate to assess the quality of preslaughter pig handling. Meat Sci. 86, 384–390.

Edwards, L.N., Engle, T.E., Grandin, T.A., Ritter, M.J., Sosnicki, A., Carlson, B.A., Anderson, D.B., 2011. The effects of distance traveled during loading, lairage time prior to slaughter, and distance traveled to the stunning area on blood lactate concentration of pigs in a commercial packing plant. Prof. Anim. Sci. 27, 485–491.

EFSA, 2011. Scientific opinion concerning the welfare of animals during transport. EFSA J. 9, 1966.

Eikelenboom, G., Bolink, A.H., Sybesma, W., 1991. Effects of feed withdrawal before delivery on pork quality and carcass yield. Meat Sci. 29, 25–30.

Ellis, M., Ritter, M.J., 2006. Management practices and meat quality. In: Proceedings of the 59th AMSA Reciprocal Meat Conference, Champaign-Urbana, IL, pp. 29–32.

Faucitano, L., 2001. Causes of skin damage to pig carcasses. Can. J. Anim. Sci. 81, 39–45.

Faucitano, L., Geverink, N.A., 2008. Effects of preslaughter handling on stress response and meat quality in pigs. In: Faucitano, L., Schaefer, A.L. (Eds.), The Welfare of Pigs - from Birth to Slaughter. Wageningen Academic Publ, Wageningen, The Netherlands, pp. 197–224.

Faucitano, L., Pedernera, C., 2016. Reception and Unloading. In: Raj, M., Velarde, A. (Eds.), Animal Welfare at Slaughter. 5m Publishing, Sheffield, UK, pp. 33–50.

Faucitano, L., Chevillon, P., Ellis, M., 2010. Effects of feed withdrawal prior to slaughter and nutrition on stomach weight, and carcass and meat quality in pigs. Livest. Sci. 127, 110–114.

Fernandez, X., Meunier-Salaun, M.-C., Ecolan, P., Mormède, P., 1995. Interactive effect of food deprivation and agonistic behaviour on blood parameters and muscle glycogen in pigs. Physiol. Behav. 58, 337–345.

Fortin, A., 2002. The effect of transport time from the assembly yard to the abattoir and resting time at the abattoir on pork quality. Can. J. Anim. Sci. 82, 141–150.

Fox, J., Widowski, T., Torrey, S., Nannoni, E., Bergeron, R., Gonyou, H.W., Brown, J.A., Crowe, T., Mainau, E., Faucitano, L., 2014. Water sprinkling market pigs in a stationary trailer. 1. Effects on pig behaviour, gastrointestinal tract temperature and trailer microclimate. Livest. Sci. 160, 113–123.

Garcia, A., McGlone, J.J., 2015. Loading and unloading finishing pigs: effects of bedding types, ramp angle, and bedding moisture. Animals. 5, 13–26.

Gentry, J.G., Johnson, A.K., McGlone, J.J., 2008. The welfare of growing- finishing pigs. In: Faucitano, L., Schaefer, A.L. (Eds.), The Welfare of Pigs: from Birth to Slaughter. Wageningen Academic Publishers, Wageningen, The Netherlands, pp. 133–161.

Gerritzen, M.A., Hindle, V.A., Steinkamp, K., Reimert, H.G.M., van der Werf, J.T.N., Marahrens, M., 2013. The effect of reduced loading density on pig welfare during long distance transport. Animal. 7, 1849–1857.

Gesing, L.M., Johnson, A.K., Selsby, J.T., Feuerbach, C., Hill, H., Faga, M., Whiley, A., Bailey, R., Stalder, K.J., Ritter, M.J., 2010. Effects of presorting on stress responses at loading and unloading and the impact on transportation losses from market-weight pigs. Prof. Anim. Sci. 26, 603–610.

Geverink, N.A., Kappers, A., Van De Burgwal, J.A., Lambooij, E., Blokhuis, H.J., Wiegant, V.M., 1998. Effects of regular moving and handling on the behavioural and physiological responses of pigs to preslaughter treatment and consequences for subsequent meat quality. J. Anim. Sci. 76, 2080–2085.

Gonyou, H.W., Brown, J., 2012. Reducing stress and improving recovery from handling during loading and transport of market pigs. Final report submitted to Alberta Livestock and Meat Agency, 40p.

Gosálvez, L.F., Averós, X., Valdelvira, J.J., Herranz, A., 2006. Influence of season, distance and mixed loads on the physical and carcass integrity of pigs transported to slaughter. Meat Sci. 73, 553–558.

Goumon, S., Bergeron, R., Faucitano, L., Crowe, T., Connor, M.L., Gonyou, H.W., 2013a. Effect of previous ramp exposure and regular handling on heart rate, ease of handling and behaviour of near market-weight pigs during a simulated loading. Can. J. Anim. Sci. 93, 461–470.

Goumon, S., Brown, J.A., Faucitano, L., Bergeron, R., Widowski, T.M., Crowe, T., Connor, M.L., Gonyou, H.W., 2013b. Effects of transport duration on maintenance behavior, heart rate and gastrointestinal tract temperature of market-weight pigs in 2 seasons. J. Anim. Sci. 91, 4925–4935.

Goumon, S., Faucitano, L., Bergeron, R., Crowe, T., Connor, M.L., Gonyou, H.W., 2013c. Effect of ramp configuration on easiness of handling, heart rate and behavior of near-market pigs at unloading. J. Anim. Sci. 91, 3889–3898.

Government of Canada, 2016. Regulations Amending the Health of Animals Regulations. Canada Gazette, vol. 150, December 3, 2016. http://gazette.gc.ca/rp-pr/p1/2016/2016-12-03/html/reg2-eng.php (accessed 10/12/2016).

GPO, 1994. Transportation of animals. United States Code 49 Sec. 80502, Suppl. 4, US Government Publishing Office. Available at: <https://www.gpo.gov/fdsys/granule/USCODE-1998-title49/USCODE-1998-title49-subtitleX-chap805-sec80502/content-detail.html>.

Grandin, T., Widowski, T., Lawlis P., 2002. Practical tips and guidelines for the handling and transport of market hogs. In: London Swine Conference, The Pork Industry in the 21st Century-Conquering the Challenges, 11–12 April, London, Canada, pp. 117–120.

Grandin, T.A., 1978. Transportation from the animal's point of view. American Society of Agricultural Engineering, Paper No. 78-6013.

Grandin, T.A., 1993. Introduction: effect of customer requirements, international standards and marketing structure on handling and transport of livestock and poultry. In: Grandin, T.A. (Ed.), Livestock Handling and Transport. CAB International, Wallingford, UK, pp. 1–18.

Grandin, T.A., 1994. Methods to reduce PSE and bloodsplash. In: Proceedings of the 21st Allen D. Leman Swine Conference, Minneapolis, MN, pp. 206–209.

Grandin, T.A., 1996. Factors that impede animal movement in slaughter plants. J. Amer. Vet. Med. Assoc. 209, 757–759.

Grandin, T.A., 1997. Assessment of stress during handling and transportation. J. Anim. Sci. 75, 245–257.

Grandin, T.A., 1998. Solving livestock handling problems in slaughter plants. In: Gregory, N.G. (Ed.), Animal Welfare and Meat Science. CABI Publications, Wallingford, UK, pp. 42–63.

Grandin, T.A., 2000. Handling and welfare of livestock in slaughter plants. In: Grandin, T.A. (Ed.), Livestock Handling and Transportation. CAB International, Wallingford, UK, pp. 409–441.

Grandin, T.A., 2002. The welfare of pigs during transport and slaughter. Available at: <http://www.grandin.com/references/pig.welfare.during.transport.slaughter.html>.

Grandin, T.A., 2008. Engineering and design of holding yards, loading ramps and handling facilities for land and sea transportation of livestock. Vet. Ital. 44, 235–245.

Grandin, T.A., Vogel, K.D., 2011. Restaurant animal welfare and humane slaughter audits in U.S. federally inspected beef and pork slaughter plants. Available at: <http://www.grandin.com/survey/2011.restaurant.audits.html>.

Griot, B., Chevillon, P., 1997. Incidence des matériels utilisés pour manipuler les porcs sur les fréquences cardiaques et les risques d'apparition d'hématomes sur carcasses. Techni-Porc. 20, 39−47.

Guàrdia, M.D., Gispert, M., Diestre, A., 1996. Mortality rates during transport and lairage in pigs for slaughter. Meat Focus Int. 10, 362−366.

Guàrdia, M.D., Estany, J., Balash, S., Oliver, M.A., Gispert, M., Diestre, A., 2004. Risk assessment of PSE condition due to pre-slaughter conditions and RYR1 gene in pigs. Meat Sci. 67, 471−478.

Guàrdia, M.D., Estany, J., Balash, S., Oliver, M.A., Gispert, M., Diestre, A., 2005. Risk assessment of DFD meat due to pre-slaughter conditions in pigs. Meat Sci. 70, 709−716.

Guàrdia, M.D., Estany, J., Balasch, S., Oliver, M.A., Gispert, M., Diestre, A., 2009. Risk assessment of skin damage due to pre-slaughter conditions and RYR1 gene in pigs. Meat Sci. 81, 745−751.

Guise, H.J., Penny, R.H.C., 1989. Factors influencing the welfare and carcass and meat quality of pigs. 1. The effects of stocking density in transport and the use of electric goads. Anim. Prod. 49, 511−515.

Guise, H.J., Penny, R.H.C., 1992. Pig welfare from farm to factory. Is there a need for more research? Pig Vet. J. 30, 16−22.

Haley, C., Dewey, C.E., Widowski, T., Poljak, Z., Friendship, R., 2008a. Factors associated with in-transit losses of market hogs in Ontario in 2001. Can. J. Vet. Res. 72, 377−384.

Haley, C., Dewey, C.E., Widowski, T., Friendship, R., 2008b. Association between in-transit losses, internal trailer temperature, and distance travelled by Ontario market hogs. Can. J. Vet. Res. 72, 385−389.

Hayne, S.M., Whittington, L.D., Gonyou, H.W., 2009. Handling stress during marketing of pigs from large groups. Available at: <www.prairieswine.com/pdf/34870.pdf>.

Hemsworth, P.H., Barnett, J.L., Hofmeyr, C., Coleman, G.J., Dowling, S., Boyce, J., 2002. The effects of fear of humans and preslaughter handling on the meat quality of pigs. Aust. J. Agric. Res. 53, 493−501.

Hoffman, L.C., Fisher, P., 2010. Comparison of the effects of different transport conditions and lairage times in a Mediterranean climate in South Africa on the meat quality of commercially crossbred Large white x Landrace pigs. J. Afr. Vet. Assess. 81, 225−227.

Johnson, A.K., Sadler, L.J., Gesing, L.M., Faga, M., Feuerbach, C., Hill, H., Bailey, R., Ritter, M.J., 2010. Effects of facility design on the stress responses and market losses of market weight pigs during loading and unloading. Prof. Anim. Sci. 26, 9−17.

Johnson, A.K., Gesing, L.M., McGlone, J.J., Berg, E., Lonergan, S.M., Fitzgerald, R., Karriker, L.A., Ramirez, A., Stalder, K.J., Sapkota, A., Kephart, R., Selsby, J.T., Sadler, L.J., Ritter, M.J., 2013. Farm and pig factors affecting welfare during the marketing process. J. Anim. Sci. 91, 2481−2491.

Jongman, E.C., Barnett, J.L., Hemsworth, P.H., 2000. The aversiveness of carbon dioxide stunning in pigs and a comparison of the CO2 stunner crate vs. the V-restrainer. Appl. Anim. Behav. Sci. 67, 67−76.

Kephart, K.B., Harper, M.T., Raines, C.R., 2010. Observations of market pigs following transport to a packing plant. J. Anim. Sci. 88, 2199−2203.

Kephart, R., Johnson, A., Sapkota, A., Stalder, K., McGlone, J.J., 2014. Establishing sprinkling requirements on trailers transporting market weight pigs in warm and hot weather. Animals. 4, 164–183.
Klont, R.E., Hulsegge, B., Hoving-Bolink, A.H., Gerritzen, M.A., Kurt, E., Winkelman-Goedhart, H.A., De Jong, I.C., Kranen, R.W., 2001. Relationships between behavioural and meat quality characteristics of pigs raised under barren and enriched housing conditions. J. Anim. Sci. 79, 2835–2843.
Lambooij, E., 2000. Transport of pigs. In: Grandin, T.A. (Ed.), Livestock Handling and Transport. CAB International, Wallingford, UK, pp. 275–296.
Lambooij, E., Engel, B., 1991. Transport of slaughter pigs by road over a long distance: some aspects of loading density and ventilation. Livest. Prod. Sci. 28, 163–174.
Lambooij, E., Garssen, G.J., Walstra, P., Mateman, F., Merkus, G.S.M., 1985. Transport of pigs by car for two days: some aspects of watering and loading density. Livest. Prod. Sci. 13, 289–299.
Leheska, J.M., Wulf, D.M., Maddock, R.J., 2003. Effects of fasting and transportation on pork quality development and extent of postmortem metabolism. J. Anim. Sci. 80, 3194–3202.
Lewis, C.R.G., McGlone, J.J., 2007. Moving finishing pigs in different group sizes: Cardiovascular responses, time and ease of handling. Livest. Sci. 107, 86–90.
Lewis, C.R.G., McGlone, J.J., 2008. Modelling feeding behaviour, rate of feed passage and daily feeding cycles, as possible causes of fatigued pigs. Animal. 2, 600–605.
Lewis, C.R.G., Hulbert, L.E., McGlone, J.J., 2008. Novelty causes elevated heart rate and immune changes in pigs exposed to handling, alleys, and ramps. Livest. Sci. 116, 338–341.
Lewis, N.J., 1999. Frustration of goal-directed behaviour in swine. Appl. Anim. Behav. Sci. 64, 19–29.
Malena, M., Voslářová, E., Kozák, A., Bělobrádek, P., Bedáňová, I., Steinhauser, L., Večerek, V., 2007. Comparison of mortality rates in different categories of pigs and cattle during transport for slaughter. Acta Vet. 76, 109–116.
Marchant-Forde, J.N., Marchant-Forde, R.M., 2009. Welfare of pigs during transport and slaughter. In: Marchant-Forde, J.N. (Ed.), The Welfare of Pigs. Springer Science + Business Media B.V, Dordrecht, The Netherlands, pp. 301–330.
McGlone, J.J., Curtis, S.E., 1985. Behavior and performance of weanling pigs in pens equipped with hide areas. J. Anim. Sci. 60, 20–24.
McGlone, J.J., McPherson, R.L., Anderson, D.L., 2004. Case study: moving devices for finishing pigs: efficacy of electric prod, board, paddle, or flag. Prof. Anim. Sci. 20, 518–523.
McGlone, J.J., Johnson, A.K., Sapkota, A., Kephart, R.K., 2014a. Establishing trailer ventilation (boarding) requirements for finishing pigs during transport. Animals. 4, 515–523.
McGlone, J.J., Johnson, A.K., Sapkota, A., Kephart, R.K., 2014b. Transport of market pigs: improvements in welfare and economics. In: Grandin, T.A. (Ed.), Livestock Handling and Transport. CABI Publications, Wallingford, UK, pp. 298–314.
Mota-Rojas, D., Becerril, M., Lemus, C., Sanchez, P., Gonzalez, M., Olmos, S.A., Ramirez, R., Alonso-Spilsbury, M., 2006. Effects of mid-summer transport duration on pre- and post-slaughter performance and pork quality in Mexico. Meat Sci. 73, 404–412.
Murray, A.C., 2001. Reducing losses from farm gate to packer. A Canadian perspective. In: Proceedings of the 1st International Virtual Conference on Pork Quality. Embrapa, Concordia, Brazil, pp. 72–84.

Nanni Costa, L., Lo Fiego, D.P., Dall'Olio, S., Davoli, R., Russo, V., 1999. Influence of loading method and stocking density during transportation on meat and dry-cured ham quality in pigs with different halothane genotypes. Meat Sci. 51, 391–399.

Nanni Costa, L., Lo Fiego, D.P., Dall'Olio, S., Davoli, R., Russo, V., 2002. Combined effects of pre-slaughter treatments and lairage time on carcass and meat quality in pigs of different halothane genotype. Meat Sci. 61, 41–47.

Nannoni, E., Widowski, T., Torrey, S., Fox, J., Rocha, L.M., Gonyou, H.W., Weschenfelder, A.V., Crowe, T., Faucitano, L., 2014. Water sprinkling market pigs in a stationary trailer. 2. Effects on selected exsanguination blood parameters and carcass and meat quality variation. Livest. Sci. 160, 124–131.

National Farm Animal Care Council, 2014. Code of Practice for the Care and Handling of Pigs: Review of Scientific Research on Priority Issues. Available at: <https://www.nfacc.ca/pdfs/codes/pig_code_of_practice.pdf>.

Newman, D., Young, J., Carr, C., Ryan, M., Berg, E., 2014. Effect of season, transport length, deck location, and lairage length on pork quality and blood cortisol concentrations of market hogs. Animals. 4, 627–642.

Nielsen, N.J., 1982. Recent results from investigations of transportation of pigs for slaughter. In: Moss, R. (Ed.), Transport of Animals Intended for Breeding, Production and Slaughter. Martinus Njhoff Publ, The Hague, The Netherlands, pp. 115–124.

NPB, 2008. Transport Quality Assurance Handbook. National Pork Board, Des Moines, IA. Available at: <http://www.pork.org/filelibrary/TQAAdvisor/TQA4Manual.pdf>.

O'Connell, N.E., Beattie, V.E., Watt, D., 2005. Influence of regrouping strategy on performance, behaviour and carcass parameters in pigs. Livest. Prod. Sci. 97, 107–115.

Olsson, I.A.H., De Jonge, F.H., Schuurman, T., Helmond, F.A., 1999. Poor rearing conditions and social stress in pigs: repeated social challenge and the effect on behavioural and physiological responses to stressors. Behav. Proc. 46, 201–215.

Peeters, E., Deprez, K., Beckers, F., De Baerdemaeker, J., Aubert, A.E., Geers, R., 2008. Effect of driver and driving style on the stress responses of pigs during a short journey by trailer. Anim. Welf. 17, 189–196.

Pereira, T.L., Conte, S., Devillers, N., Sommavilla, R., Friendship, R., Guay, F., Dalla Costa, F.A., Titto, E.A.L., Faucitano, L., 2016. Effects of ventilation and water misting on the physiological response of pigs kept in a stationary trailer before unloading. J. Anim. Sci. 94, 41.

Pérez, M.P., Palacio, J., Santolaria, M.P., Aceña, M.C., Chacón, G., Gascón, M., Calvo, J.H., Zaragoza, P., Beltran, J.A., Garcia- Belenguér, S., 2002. Effect of transport time on welfare and meat quality in pigs. Meat Sci. 61, 425–433.

Perremans, S., Randall, J.M., Allegaert, L., Stiles, M.A., Rombouts, G., Geers, R., 1998. Influence of vertical vibration on heart rate of pigs. J. Anim. Sci. 76, 416–420.

Pilcher, C.M., Ellis, M., Rojo-Gómez, A., Curtis, S.E., Wolter, B.F., Peterson, C., Ritter, M. J., Brinkmann, J., 2011. Effects of floor space during transport and journey time on indicators of stress and transport losses of market-weight pigs. J. Anim. Sci. 89, 3809–3818.

Rabaste, C., Faucitano, L., Saucier, L., Foury, D., Mormède, P., Correa, J.A., Giguère, A., Bergeron, R., 2007. The effects of handling and group size on welfare of pigs in lairage and its influence on stomach weight, carcass microbial contamination and meat quality variation. Can. J. Anim. Sci. 87, 3–12.

Rademacher, C., Davies, P., 2005. Factors associated with the incidence of mortality during transport of market hogs. In: Proceedings of the Allen D. Leman Swine Conference, St. Paul, MN, pp. 186–191.

Randall, J.M., Duggan, J.A., Alami, M.A., 1995. Influence of motion and vibration of animals. Fleischwirt. 75, 201–204.

Randall J.M., Stiles M.A., Geers R., Schutte A., Christensen L., Bradshaw R.H., 1996. Vibration on pig transporters: implications for reducing stress. Proceedings of the EU-Seminar: New information on welfare and meat quality of pigs as related to handling, transport and lairage conditions, Landbauforschung Völkenrode, vol. 166, pp. 143–159.

Riches, H.L., Guise, H.J., Penny, R.H.C., 1996. A national survey of transport conditions for pigs. Pig J. 38, 8–18.

Ried, R.L., Mills, S.C., 1962. Studies of carbohydrate metabolism metabolism of sheep. XVI: The adrenal response to physiological stress. Aust. J. Agric. Res. 13, 282–294.

Ritter, M.J., Ellis, M., Brinkmann, J., DeDecker, J.M., Keffaber, K.K., Kocher, M.E., Peterson, B.A., Schlipf, J.M., Wolter, B.F., 2006. Effect of floor space during transport of market-weight pigs on the incidence of transport losses at the packing plant and the relationships between transport conditions and losses. J. Anim. Sci. 84, 2856–2864.

Ritter, M.J., Ellis, M., Bertelsen, C.R., Bowman, R., Brinkmann, J., DeDecker, J.M., Keffaber, K.K., Murphy, C.M., Peterson, B.A., Schlipf, J.M., Wolter, B.F., 2007. Effects of distance moved during loading and floor space on the trailer during transport on losses of market weight pigs on arrival at the packing plant. J. Anim. Sci. 85, 3454–3461.

Ritter, M.J., Ellis, M., Bowman, R., Brinkmann, J., Curtis, S.E., DeDecker, J.M., Mendoza, O., Murphy, C.M., Orellana, D.G., Peterson, B.A., Rojo, A., Schlipf, J.M., Wolter, B.F., 2008a. Effects of season and distance moved during loading on transport losses of market-weight pigs in two commercially available types of trailer. J. Anim. Sci. 86, 3137–3145.

Ritter, M.J., Ellis, M., Murphy, C.M., Peterson, B.A., Rojo, A., 2008b. Effects of handling intensity, distance moved, and transport floor space on the stress responses of market weight pigs. J. Anim. Sci. 86, 43.

Ritter, M.J., Ellis, M., Berry, N.L., Curtis, S.E., Anil, L., Berg, E., Benjamin, M., Butler, D., Dewey, C., Driessen, B., DuBois, P., Hill, J.D., Marchant-Forde, J.N., Matzat, P., McGlone, J.J., Mormede, P., Moyer, T., Pfalzgraf, K., Salak-Johnson, J., Siemens, M., Sterle, J., Stull, C., Whiting, T., Wolter, B., Niekamp, S.R., Johnson, A.K., 2009. Transport losses in market weight pigs: I. A review of definitions, incidence, and economic impact. Prof. Anim. Sci. 25, 404–414.

Rocha, L.M., Velarde, A., Dalmau, A., Saucier, L., Faucitano, L., 2016. Can the monitoring of animal welfare parameters predict pork meat quality variation through the supply chain (from farm to slaughter)? J. Anim. Sci. 94, 359–376.

Salmi, B., Trefan, L., Bünger, L., Doeschl-Wilson, A., Bidanel, J.P., Terlouw, C., Larzul, C., 2012. Bayesian meta-analysis of the effect of fasting, transport and lairage times on four attributes of pork meat quality. Meat Sci. 90, 584–598.

SCAHAW, 2002. The Welfare of Animals during Transport (Details for Horses, Pigs, Sheep and Cattle). Report of the Scientific Committee on Animal Healh and Animal Welfare, European Commission, 130p.

Scheeren, M.B., Gonyou, H.W., Brown, J., Weschenfelder, A.V., Faucitano, L., 2014. Effects of transport time and location within truck on skin bruises and meat quality of market weight pigs in two seasons. Can. J. Anim. Sci. 94, 71–78.

Schutte A., Mergens A., Pott U., Venthien S., 1996. Effect of transport conditions (straw; stoppage) and unloading procedures on physiological and meat quality. Proceedings of the EU-Seminar: New information on welfare and meat quality of pigs as related to handling, transport and lairage conditions, Landbauforschung Völkenrode, vol. 166, pp. 117–132.

Schwartzkopf Genswein, K., Faucitano, L., Dadgar, S., Shand, P., Gonzàlez, L.A., Crowe, T., 2012. Road transport of cattle, swine and poultry in North America and its impact on animal welfare, carcass and meat quality: a review. Meat Sci. 92, 227–243.

Scroggs, L.V., Kattesh, H.G., Morrow, J.L., Stalder, K.J., Dailey, J.W., Roberts, M.P., Schneider, J.F., Saxton, A.M., 2002. The effects of split marketing on the physiology, behaviour, and performance of finishing swine. J. Anim. Sci. 80, 338–345.

Standards of China Association for Standardization, 2014. Farm Animal Welfare Requirements: Pigs. China Association for Standardization 235–2014, 32p.

Stephens, D.B., Perry, G.C., 1990. The effects of restraint, handling, simulated and real transport in the pig (with reference to man and other species). Appl. Anim. Behav. Sci. 28, 41–55.

Stewart, G., Ritter, M.J., Culbertson, M., Mann, G., Wofford, R., 2008. Effects of previous handling and feed withdrawal prior to loading on transport losses in market weight pigs. In: Proceedings of the 2008 American Association of Swine Veterinarians, San Diego, CA, pp. 359–362.

Sunstrum, J., Dewey, C., Haley, C., 2006. Clinical signs of stress of finisher pigs transported to market in the summer. In: Proceedings of the 2006 American Association of Swine Veterinarians, Orlando, FL, p. 45.

Sutherland, M.A., McDonald, A., McGlone, J.J., 2009. Effects of variations in the environment, length of journey and type of trailer on the mortality and morbidity of pigs being transported to slaughter. Vet. Rec. 165, 13–18.

Tarrant, P.V., 1989. The effects of handling, transport, slaughter and chilling on meat quality and yield in pigs - a review. Ir. J. Food Sci. Technol. 13, 79–107.

Terlouw, C., 2005. Stress reactions at slaughter and meat quality in pigs: genetic background and prior experience: a brief review of recent findings. Livest. Prod. Sci. 94, 125–135.

Terlouw, C., Berne, A., Astruc, T., 2009. Effect of rearing and slaughter conditions on behaviour, physiology and meat quality of Large White and Duroc-sired pigs. Livest. Sci. 122, 199–213.

Tönepöhl, B., Appel, A.K., Welp, S., Vos, B., von Borstel, U.K., Gauly, M., 2012. Effects of marginal environmental and social enrichment during rearing on pigs' reactions to novelty, conspecifics, and handling. Appl. Anim. Behav. Sci. 46, 57–65.

Torrey, S., Bergeron, R., Gonyou, H.W., Widowski, T., Lewis, N., Crowe, T., Correa, J.A., Brown, J., Faucitano, L., 2013a. Transportation of market-weight pigs 1. Effect of season and truck type on behavior with a 2 hour transport. J. Anim. Sci. 91, 2863–2871.

Torrey, S., Bergeron, R., Faucitano, L., Widowski, T., Lewis, N., Crowe, T., Correa, J.A., Brown, J., Gonyou, H.W., 2013b. Transportation of market-weight pigs 2. Effect of season and animal location in the truck on behavior with a 8 hour transport. J. Anim. Sci. 91, 2872–2878.

Van de Perre, V., Permentier, L., De Bie, S., Verbeke, G., Geers, R., 2010. Effect of unloading, lairage, pig handling, stunning and season on pH of pork. Meat Sci. 86, 931–937.

Van Putten, G., Elshof, W.J., 1978. Observations on the effect of transportation on the well-being and lean quality of slaughter pigs. Anim. Reg. St. 1, 247–271.

Velarde, A., Dalmau, A., 2017. Slaughter of pigs. In: Špinka, M. (Ed.), Advances in Pig Welfare. Woodhead Publishing, Duxford, UK.

Vecerek, V., Malena, M., Malena Jr., M., Voslarova, E., Chloupek, P., 2006. The impact of the transport distance and season on losses of fattened pigs during transport to the slaughterhouse in the Czech Republic in the period from 1997 to 2004. Vet. Med. 51, 21–28.

Viau, J., Champagne, D., 1998. La mise à jeun chez le porc avant l'abattage. Report of Centre de développement du Porc du Québec, Québec, Canada.

Vitali, A., Lana, E., Amadori, M., Bernabucci, U., Nardone, A., Lacetera, N., 2014. Analysis of factors associated with mortality of heavy slaughter pigs during transport and lairage. J. Anim. Sci. 92, 5134–5141.

Warriss, P.D., 1994. Antemortem handling of pigs. In: Cole, D.J.A., Wiseman, T.J., Varley, M.A. (Eds.), Principles of Pig Science. Nottingham University Press, Sutton Bonnington, UK, pp. 425–432.

Warriss, P.D., 1995. Pig handling-guidelines for the handling of pigs antemortem. Meat Focus Int. 4, 491–494.

Warriss, P.D., 1996. The consequences of fighting between mixed groups of unfamiliar pigs before slaughter. Meat Focus Int. 5, 89–92.

Warriss, P.D., Bevis, E.A., Edwards, J.E., Brown, S.N., Knowles, T.G., 1991. Effect of the angle of slope on the ease with which pigs negotiate loading ramps. Vet. Rec. 128, 419–421.

Warriss, P.D., Brown, S.N., Knowles, T.G., Edwards, J.E., 1992. Influence of width and bends on the ease of movement of pigs along races. Vet. Rec. 130, 202–204.

Warriss, P.D., Brown, S.N., Knowles, T.G., Edwards, J.E., Kettlewell, P.J., Guise, H.J., 1998. The effect of stocking density in transit on the carcass quality and welfare of slaughter pigs: 2. Results from the analysis of blood and meat samples. Meat Sci. 50, 447–456.

Warriss, P.D., Brown, S.N., Knowles, T.G., Wilkins, L.J., Pope, S.J., Chadd, S.A., Kettlewell, P.J., Green, N.R., 2006. Comparison of the effects of fan-assisted and natural ventilation of vehicles on the welfare of pigs being transported to slaughter. Vet. Rec. 158, 585–588.

Weeks, C.A., 2008. A review of welfare in cattle, sheep, and pig lairages, with emphasis on stocking rates, ventilation and noise. Anim. Welf. 17, 275–284.

Werner, C., Reiners, K., Wicke, M., 2007. Short as well as long transport duration can affect the welfare of slaughter pigs. Anim. Welf. 16, 385–389.

Weschenfelder, A.V., Torrey, S., Devillers, N., Crowe, T., Bassols, A., Saco, Y., Piñeiro, M., Saucier, L., 2012. Effects of trailer design on animal welfare parameters and carcass and meat quality of three Pietrain crosses being transported over a long distance. J. Anim. Sci. 90, 3220–3231.

Weschenfelder, A.V., Torrey, S., Devillers, N., Crowe, T., Bassols, A., Saco, Y., Piñeiro, M., Saucier, L., Faucitano, L., 2013. Effects of trailer design on animal welfare parameters and carcass and meat quality of three Pietrain crosses being transported over a short distance. Livest. Sci. 157, 234–244.

Zanella, A.J., Duran, O., 2000. Pig welfare during loading and transportation: a North American perspective. In: Proceedings of the 1st International Virtual Conference on Pork Quality. Embrapa, Concordia, Brazil, pp. 20–31.

Slaughter of pigs

10

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10.1 Introduction

Slaughter of pigs for human consumption remains to be a sensitive issue. After arrival at the abattoir, pigs are unloaded and held in pens before slaughter. Afterwards, pigs are moving the slaughter area for stunning and slaughtering. Humane slaughter regulations, standards or guidelines implemented around the world, including that of the World Organisation for Animal Health (OIE, 2009), consider pigs as sentient beings and therefore require that any avoidable pain, distress or suffering shall be spared during their killing and related operations.

10.2 Lairage

During lairage, animals are exposed simultaneously to a variety of stressors that may result in high levels of psychological and physical stress (Grandin, 1997), thus compromising their welfare. These potential stressors include fasting and water deprivation, mixing of unfamiliar individuals, handling by humans, exposure to a novel environment, noise, forced physical exercise and extremes of temperature and humidity. To avoid the negative welfare effects of lairage, animals should be unloaded as quickly as possible after arrival and subsequently slaughtered without undue delay. However, current abattoirs cannot afford any interruption in the supply of livestock to the slaughter line, and try always to have a sufficient reserve of stock waiting in the holding pens. Furthermore, lairage at slaughter permits animals to recover from the stress and activity resulting from transport and unloading, which in some situations can be beneficial to meat quality and welfare. However, the benefit of providing animals with a resting time can be lost if the animals are subjected to poor handling and stressful environmental conditions in lairage. To safeguard animal welfare, both lairage resources and management should guarantee the basic requirements for animal welfare.

During transport, animals are usually deprived of water and food, with the risk of experiencing thirst and hunger during lairage. In the lairage, thirst is usually corrected by allowing the animals to drink. Therefore, water should always be available and a water supply system designed and constructed to allow all animals easy access (i.e. in terms of comfortable drinking height and number of water troughs or drinkers) to clean water at all times. Hence, the drinking facilities should be

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designed so that the risk of the water becoming contaminated with faeces or urine is minimised (e.g. nipples maintain the water cleaner than troughs or buckets).

Pigs are fasted to reduce gut content during the preslaughter period and so prevent the release and spread of bacterial contamination through faeces within the group during transport and lairage as well as through the spillage of gut contents during carcass evisceration (Faucitano and Geverink, 2008). Fasting before slaughter, within reasonable limits, is also beneficial to the welfare condition of the pig as it prevents pigs from vomiting in transit and developing hyperthermia (Faucitano and Goumon, Chapter 9: Transport of pigs to slaughter and associated handling). However, an extended fasting period causes hunger and aggressiveness (Warriss, 1994). In pigs, fat mobilisation, as the main source of energy, starts after about 16 hours starvation. Currently, a maximal feed withdrawal of 16–24 hours before slaughter (including time on farm, transport and lairage) is recommended. After this time, animals should be fed with moderate amounts of food. EU legislation states that animals must be fed if the lairage time exceeds 12 hours (Regulation No. 1099/2009). This normally occurs with an overnight stay.

Pigs have great difficulty in losing heat and may therefore suffer from heat stress at ambient temperatures close to the upper limit of their thermoneutral zone and at high humidity. Lying behaviour is an important tool within behavioural thermoregulation, and therefore related to the effective temperature of the environment (Velarde et al., 2007). In thermoneutral conditions, pigs lie in sternal recumbency or on their side and touching each other. When it is too warm, pigs lie down quickly in lateral position, maintain relatively wide separation between individuals (Fig. 10.1) and increase their respiration rate (Santos et al., 1997). Lairage conditions of 15–18°C and 59%–65% relative humidity (Honkavaara, 1989) and provision of appropriate shelter and ventilation are recommended to reduce thermal stress. During hot weather, the practice of spraying pigs with cold water (10–12°C)

Figure 10.1 Lying behaviour in warm environments.

at lairage limits the risk of hyperthermia and consequently reduces the mortality rate in lairage pens (Faucitano and Geverink, 2008). Showering reduces also aggressive behaviour and facilitates greater ease of handling into the stunning chute. The shower regime should be intermittent (i.e. once at arrival and once just before moving to stunning) and not for long times (i.e. 10–30 minutes can be enough in most cases) in order to get the greatest cooling effect and reduce activity and aggression. To optimise the cooling effect, the spray of the sprinklers should penetrate the hair and wet the skin. Sprinklers that create a fine mist can increase environmental relative humidity without penetrating the hair. Below an environmental temperature of 5°C showering is not recommended as it causes thermogenesis by shivering to maintain body temperature.

Holding animals in pens gives them a rest period after the journey. Nevertheless, to achieve this, the lairage environment should allow the animal to satisfy its needs for comfort around resting and thermal comfort (neither too hot nor too cold) as well as providing enough space for the animal to be able to move around freely. To satisfy its need of comfort around resting, each animal shall have enough space to stand up, lie down and turn around. For instance, a pig of 100 kg liveweight needs a space allowance of 0.40 m^2 for lying in sternal recumbency. Taking into account that some extra space is needed for other activities (i.e. move to the drinker or social interactions), 0.5 m^2 for each pig will be the minimum space allowance needed under these circumstances. When the temperature increases (above 25°C), the animals will tend to rest in lateral recumbency and the space required for a pig of 100 kg to lie in this position is around 1.00 m^2. Under these circumstances, the space allowance will be 1.10 m^2/100 kg live weight pig. Therefore, if the slaughterhouse does not provide systems to cope with heat stress (such as showers or fans) and pigs shows resting behaviour with lateral recumbency, the space allowance should be increased accordingly.

Mixing unacquainted pigs is usually followed by fighting and mounting behaviour, impairing animal welfare and carcass quality (Fig. 10.2). If mixing is unavoidable, the recommendation is to mix pigs just prior to loading or on the transport vehicle rather than later in the slaughterhouse, and to maintain in lairage the same groups from the transport.

Lighting and artificial illumination in the lairage area should be enough to inspect the animals and allow them to move without fear and distress. Pigs are very sensitive to high-frequency sounds, and noise is a potential stressor. Sudden and high-pitched sounds, such as gates clanging and pig vocalisation (80–103 dB; Weeks, 2008; Weeks et al., 2009) can be a source of stress, as shown by increased blood lactate, creatine phosphokinase (CPK), cortisol levels and heart rate (Talling at al., 1996; Kanitz et al., 2005).

Several studies (Honkavaara, 1989; Warriss et al., 1992; Brown et al., 1999; Pérez et al., 2002) concluded that 2–3 hours in lairage permits pigs to recover from stress resulting from transport and unloading and will be enough to reduce the incidence of PSE meat. Furthermore, Van de Perre et al. (2010) recommends reducing the lairage time to less than 2 hours in winter, and to less than 0.5 hour in pigs subjected to heat stress during lairage. Other studies show little effect of lairage

Figure 10.2 Fighting due to mixing.

duration on meat quality when pigs are free of the halothane gene and subjected to good transport conditions (Aaslying and Barton Gade, 2001; Geverink et al., 1996).

10.3 Moving to the stunning area

Moving animals forward to the stunning point is a very important source of pain, fear and stress. To follow the speed of the slaughter line, animals are moved quickly through the raceway. The combination of higher speeds and poorly designed handling systems (i.e. slippery floors, with distractions that make animals balk, dark and bad maintained corridors, sharp edges, etc.) is detrimental to animal welfare as handling animals at this rate requires considerable coercion and triggers the use of goad implements and sticks. Shocking pigs with electric goads results in pain and significantly raises heart rate, open mouth breathing and many other physiological indicators of acute distress. The routine use of electric goads is also a sign of poor attitude of the stockperson. The use of an electric prod with the power turned off was associated with the attitude of abattoir personnel to have a positive interaction with animals, whereas if turned on it was associated with a negative interaction (Faucitano and Geverink, 2008). Flags, paddles and plastic boards can be considered good alternatives to the use of electric prods, although their effectiveness depends on the personnel using it (training and attitudes) and the design of the facilities, as mentioned above.

10.4 Bleeding

Pigs are usually bled by chest sticking with incision of the brachiocephalic trunk and the major blood vessels, which arise from the heart. With an adequate incision, pigs lose between 40% and 60% of their total blood volume, and within 30 seconds the amount of blood lost is 70%–80% of the total amount of blood which will be lost (Warriss and Wilkins, 1987). The time to loss brain responsiveness (based on reduction in visual evoked responses) ranges between 14 and 23 seconds (mean 18, SD: ± 3) and the development of an isoelectric electrocorticogram (ECoG) between 22 and 30 seconds (Wotton and Gregory, 1986). This time might increase if the section of the main blood vessels are incomplete. The duration of unconsciousness induced by any stunning method should be longer than the sum of the time interval between the end of stun and sticking and the time it takes for blood loss to cause death. Chest sticking should therefore be performed quickly after the stun and to ensure rapid onset of death.

10.5 Stunning

Regulation (EC) No. 1099/2009 defines stunning as any intentionally induced process which causes loss of consciousness and sensibility without pain, including any process resulting in instantaneous death. Consciousness is a state of awareness and ranges from waking through sleep until unconsciousness is reached. The reticular formation in the brain stem (involved also in vital functions such as breathing and heart activity) is associated with the level of consciousness (EFSA, 2013a). This structure stimulates many cortical regions via projections called the ascending reticular activating system (Munk et al., 1996; Parvizi and Damasio, 2001; Brown et al., 2012). Loss of consciousness is induced by a temporary or permanent damage to brain function that makes the animal unable to perceive external stimuli (which is referred to as insensibility) and control its voluntary mobility and, therefore, respond to normal stimuli, including pain (EFSA, 2004). Lesions in the reticular formation or in the ascending reticular activating system result in unconsciousness characterised by the complete absence of wakefulness and responsiveness to external stimuli (Laureys et al., 2004; Bateman, 2001).

In order to fulfil the humane slaughter requirements, the duration of unconsciousness must be longer than the sum of time that lapses between the end of stun and the time to onset of death that occurs through blood loss after slaughter or through the induction of cardiac arrest. Regulation requires that animals must be dead before any carcass dressing or scalding operations begin. Under laboratory conditions, the induction and maintenance of unconsciousness following stunning can be ascertained by recording the brain activity using electroencephalography (EEG) or electrocorticography (ECoG). Induction of unconsciousness is normally recognised from the predominance of slow-wave (low frequency) and high-amplitude EEG activity followed by a quiescent EEG (EFSA, 2013). When stunning-induced EEG or ECoG changes are ambiguous, abolition of auditory, somatosensory or visual evoked potentials in the brain has been used to ascertain the brain responsiveness to these external stimuli. Under field conditions, the effectiveness of stunning can be recognised from the characteristic changes in the behaviour of animals (e.g. loss of posture), physical signs (e.g. onset of seizures, cessation of breathing, fixed eye) and from the presence or absence of response to physiological reflexes (e.g. response to an external stimulus such as blinking response to touching the cornea (corneal reflex), response to pain stimulus such as nose prick or toe pinching). In the scientific literature, these physical signs and reflexes have been referred to as indicators of unconsciousness or consciousness and used to monitor welfare at slaughter of animals (EFSA, 2004). The EFSA AHAW panel has developed toolboxes of welfare indicators for developing monitoring procedures at slaughterhouses for pigs stunned with head-only electrical method or carbon dioxide at high concentration (EFSA, 2013b). In particular, it proposed welfare indicators together with their corresponding outcomes of consciousness, unconsciousness or death. The toolbox of indicators is proposed to be used to assess consciousness at three key stages of monitoring: (1) after stunning and during shackling and hoisting, (2) during sticking, and (3) during bleeding. The frequency of checking differs between the roles of different people with responsibility for ensuring animal welfare at slaughter. The personnel performing stunning, shackling, hoisting and/or bleeding, will have to check all the animals and confirm that they are not conscious following stunning. For the Animal Welfare Officer (AWO), who has the overall responsibility for animal welfare, a mathematical model for the sampling protocols is proposed, giving some allowance to set the sample size of animals that he/she needs to check at a given throughput rate (total number of animals slaughtered in the slaughterhouses) and tolerance level (amount of potential failures—animals that are conscious after stunning; animals that are not unconscious or not dead after slaughter without stunning). The model can also be applied to estimate threshold failure rate at a chosen throughput rate and sample size.

Additionally, the EU project 'Coordinated European Animal Welfare Network (www.euwelnet.eu)' developed standard operating procedures (SOPs) for the valid and reliable assessment of unconsciousness following gas stunning in pig, which enable food business operators (FBO) and AWOs to ensure compliance with the technical challenges arising from implementation of the Regulation (EC) 1099/2009 and to provide the competent authorities (CAs) and official veterinarians (OVs) with a method to assess compliance.

10.6 Stunning methods

The most commonly used methods for stunning pigs are electrical stunning and exposure to carbon dioxide at high concentration. Table 10.1 shows the effective use, advantages and disadvantages of both stunning methods.

10.6.1 Electrical stunning

Electrical stunning involves application of an electric current of sufficient magnitude to the brain such that a generalised epileptiform activity is induced, similar to that recorded in humans during grand mal epileptic seizures (Croft, 1952;

Table 10.1 **Effective use, advantages and disadvantages of stunning methods**

	Stunning method	
	Electrical stunning	**Gas stunning**
Effective use	• Sufficient amount of electric current through the brain (>1.3 A). • Proper restraining to facilitate uninterrupted flow of current. • Electrodes shall span the brain and be adapted to its size. • Bleeding performed while the animal is in the tonic phase	• The gas concentrations must be continuously monitored and maintained at the prescribed levels • Pigs should be able to stand in a normal position and breathe without restraint. • Prolonged exposure may result in irreversible stunning, and eliminate the chances of recovery of consciousness. • The concentration of carbon dioxide and duration of exposure determines the duration of unconsciousness or the onset of death.
Advantages	• Immediate loss of consciousness • Head to body electrical stunning provokes death and stun-to-stick interval is not critical in this case.	• Restraint during stunning is not necessary. • Animals are stunned in groups with the minimum amount of restraint and handling stress. • It is possible to have variable stun-to-stick intervals as the increasing duration of exposure to the gas mixture increases the duration of unconsciousness and onset of death. • The use of anoxic gases (Ar or N_2) to induce hypoxia is non-aversive and does not induce sense of breathlessness before loss of consciousness occurs.
Disadvantages	• Restraint of animal is needed to facilitate correct placement of the electrodes which can be distressing. • Duration of unconsciousness can be short after head-only stunning. • Use of inadequate electrical parameters and/or inappropriate electrode placement would cause pain and distress.	• The loss of consciousness is not immediate. • The induction of unconsciousness with carbon dioxide mixtures is aversive and distressing to animals. • The induction of unconsciousness with anoxic gases takes queried prolonged exposure times to induce unconsciousness and death.

Hoenderken, 1978). This seizure-like state, immediately followed by an exhausted state, is suggestive of an immediate loss of consciousness and appears to be associated with a lack of sensory awareness, which lasts a finite period of time (Anil, 1991). The epileptiform activity is induced by an increase in the release of several excitatory neurotransmitters (e.g. glutamate and aspartate) into the extracellular space (Cook et al., 1992). These changes are transient and if the animal is not slaughtered immediately and allowed to recover from the seizure-like state, it will start regaining consciousness about 40 seconds after the stun (Anil, 1991). As electrical stunning is reversible, it should be followed as soon as possible by a procedure ensuring death. The onus of preventing resumption of consciousness in effectively stunned animals relies on the efficiency of slaughter (bleeding) procedure; i.e. the prompt and accurate severance of the brachiocephalic artery that supplies oxygenated blood to the brain.

Electrical stunning is normally applied by placing the tongs between the eyes and the base of the ears (Fig. 10.3) on both sides of the head (Velarde et al., 2000). The main determinant of the epileptiform activity is considered to be the amount of current flowing through the cerebral cortex (Hoenderken, 1978). In pigs, the minimum currents required for an effective stun is 1.3 A. Ohm's Law defines the relationship between current, voltage and resistance. The administered current is a function of the amount of voltage and inversely proportional to the electrical resistance of the stunning tongs and tissues (i.e. dryness of skin, thickness of subcutaneous fat and skull bone density and thickness) in the current pathway between both stunning electrodes.

With constant voltage stunners, the amount of current delivered to the animal varies due to variation of the total impedance or resistance in the pathway between the electrodes. In this case, the current starts to flow from zero to the maximum, which would take certain time depending upon the voltage. The time taken to breakdown this resistance seems to be shorter when high voltages (250 V or more)

Figure 10.3 Head-only electrical stunning applied manually or automatically.

are employed. Application of a voltage lower than that is required to breakdown the electrical resistance in this pathway and hence deliver currents lower that the threshold necessary to induce grand mal epilepsy or when the current does not pass through the brain due to shunting between the electrodes over the surface of the skull will induce a potentially painful arousal or seizures rather than unconsciousness.

By contrast, constant current stunners are designed and constructed in such a way that they anticipate high resistance in the pathway and hence start with the maximum available voltage, which is usually in excess of 250 V. Owing to this, the target current is reached within the first few current cycles and the applied voltage may also be modulated according to the changes in the resistance. Therefore, constant current stunners are preferred to constant voltage stunners on animal welfare grounds. The most common electrical stunning methods use 50 Hz sine wave alternating current (AC) frequency. Higher frequencies, although reducing the muscle stimulation and improving meat quality, require higher voltages to induce epilepsy and the duration of epilepsy is also shorter.

Stunning equipment shall be fitted with devices displaying the delivered voltage and current during each stunning application and with an acoustic and/or optic signals, to indicate an interrupted stun, excessively short stun duration and/or increase in total electrical resistance in the pathway (due to dirt, fleece or carbonisation), which could lead to insufficient current flow and inadequate stunning. Such devices would facilitate effective monitoring of electrical stunning.

Head-only electrical stunning might be immediately followed by a second current applied across the chest to induce cardiac ventricular fibrillation that severely impairs cardiac output (reduced to $<30\%$ of normal) and normal blood circulation. Consequently, it induces hypoxia in the brain and myocardium, which prolongs the period of unconsciousness induced by the head-only electrical stun and leads to death (Von Mickwitz et al., 1989), even if it is not bled out (irreversible stunning). Therefore, stun-to-stick interval is not critical. Cardiac ventricular fibrillation may be induced using a single application such that one electrode is placed on the forehead and the other on the body of the animal behind the position of the heart or a two-applications system such that a head-only current application is immediately followed by a transthoracic or head-to-body application of the current. High frequencies do not produce the cardiac ventricular fibrillation, but they may reduce muscle spasms and convulsions. Therefore, first (head-only) current can be applied high frequencies but the second current should be applied using a 50 Hz sine wave alternating current that is more effective in inducing cardiac ventricular fibrillation.

Several automatic electrical stunning methods are currently available. One device consists of a V-type restrainer where each pig makes contact with the electrodes and receives the stunning current. During stunning, the animals are turned out and fall onto a table. A second method also uses a conveyor belt system; at the end of the restrainer the nose of the pigs interrupts a beam of light, which activates the electrodes. The electrodes are positioned between the eye and ear. After 1 second of stunning, a heart electrode is positioned behind the left shoulder and current delivered for 1.5 seconds. As a result of the body current, the animals do not show muscle contractions.

The recommended indicators to monitor head-only electrical stunning are presented in Fig. 10.4 (EFSA, 2013b). Effective stunning induces tonic and clonic (kicking) seizures, which are the outward symptoms of grand mal epilepsy. Following the stun, the hind legs are flexed under the abdomen and the forelegs fully extended. The body is tense and tonic (rigid), breathing is absent and the eyeballs may be rotated to a great extent that the pupils may not be visible. The clonic phase, which can be either a galloping, cantering or erratic kicking action, follows usually immediately after the tonic phase (Anil, 1991; Gregory, 1998). Therefore, the recommended indicators for monitoring after head-only electrical stunning application (in Toolbox 1) are tonic/clonic seizures, breathing and the corneal or palpebral reflex. Additionally, spontaneous blinking, posture and vocalisations may be used. At sticking (Toolbox 2), the recommended indicators to be used are breathing, tonic/clonic seizures and muscle tone. Additionally, the corneal or palpebral reflex, spontaneous blinking and vocalisations may be used. During bleeding (Toolbox 3) the recommended indicators are breathing and muscle tone. Additionally, vocalisations, the corneal or palpebral reflex and spontaneous blinking may be used. The most common intervention to apply if there is a risk of consciousness is firstly to re-stun and secondly to evaluate the risk factors for ineffective stunning.

10.6.2 Gas stunning

The most widely used gas stunning method is exposure to concentrations of carbon dioxide (CO_2) higher than 80% by volume in air (hypercapnia) and in a lesser extent mixtures of less than 30% by volume of CO_2 in argon (Ar) or nitrogen (N_2) or both with up to 5% by volume of residual oxygen (O_2) (hypercapnic hypoxia). Exposure of animals to gas mixtures leads to inhibition of neurone activity leading to progressive loss of brain function, and hence, gradual loss of consciousness (EFSA, 2004). Gas mixtures containing carbon dioxide induces hypercapnia and inhibit neurones through acidosis. During CO_2 inhalation, the O_2 of erythrocytes becomes displaced by CO_2 and, as a direct consequence, pO_2 and $SatO_2$ decrease progressively. The respiratory and metabolic acidosis induced, reduces the pH of cerebrospinal fluid (CSF), which bathes the brain and spinal cord, and neurons thereby exerting its neuronal inhibitory and anaesthetic effects (Woodbury and Karler, 1960). Consequently, the animal loses consciousness. Normal pH of CSF is 7.4 and unconsciousness begins when the CSF pH falls below 7.1 and reaches a maximum at pH 6.8. Whereas hypoxia occurring as a result of the inhalation of Ar or N_2 induces unconsciousness by depriving the brain of oxygen. Cerebral dysfunction occurs when the partial pressure of oxygen in cerebral venous blood falls below 19 mmHg. The depletion of O_2 causes neuronal depolarisation and intracellular metabolic crisis leading to cellular death in neurons (Rosen and Morris, 1991; Huang et al., 1994). The mechanism of induction of unconsciousness by hypoxia is due to the inhibition of *N*-methyl-D-aspartate (NMDA) receptor channels in the

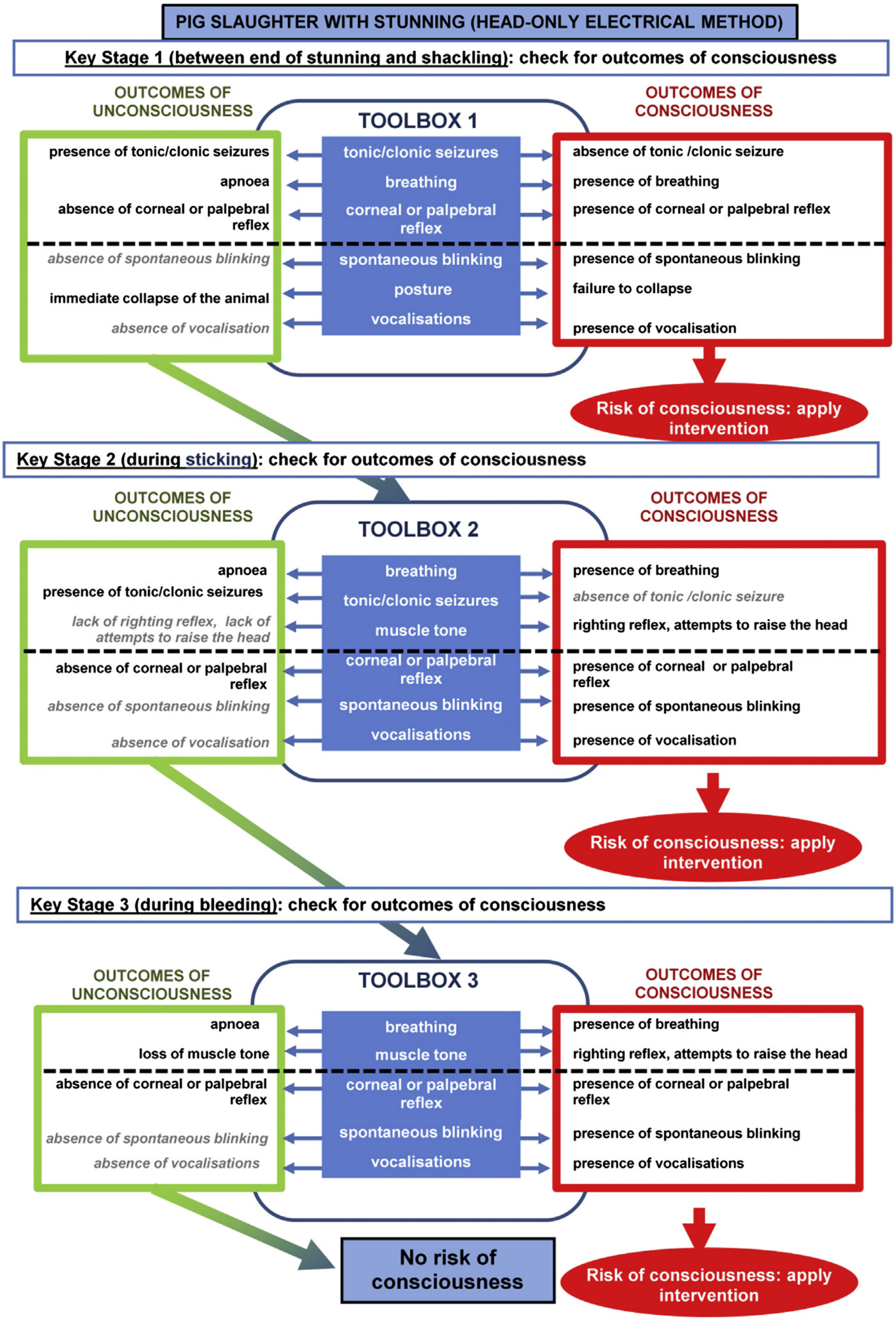

Figure 10.4 Toolbox for monitoring welfare at slaughter of pigs following head-only electrical stunning. (The indicators below the dashed line are also proposed, but their sensitivity or feasibility is lower and they should not be relied upon solely.)

brain, which is essential for maintaining neuronal arousal during conscious state (EFSA, 2004).

As CO_2 does not induce immediate loss of consciousness, inhalation of concentrations greater than 30% of carbon dioxide (CO_2) by volume in atmospheric air causes aversion, irritation of the mucous membranes (which can be painful) and respiratory distress during the induction phase (Velarde et al., 2007). During CO_2 exposure, pigs show signs of aversion such as retreat attempts, headshaking, sneezing, breathlessness, freezing, escape attempts, gasping (a very deep breath through a gaping-open mouth, indicative of breathlessness; Raj and Gregory 1996), and vocalisations (Holst, 2001; Velarde et al., 2007). In contrast to hypercapnia, hypoxia does not cause aversion prior to loss of consciousness. The time to induce unconsciousness when exposed to anoxia is longer than when exposed to hypercapnia (Raj et al., 1997). Raj and Gregory (1995) reported that the addition of CO_2 to a hypoxic atmosphere reduces the time needed to induce unconsciousness. However, according to Raj and Gregory (1995), the CO_2 concentration of the gas mixture should be below 30% in the atmosphere in order to avoid aversion. The time to loss of consciousness occurring during exposure of animals to gas mixture depends upon the composition of the gas mixtures. The exposure of pigs to either argon induced anoxia or the carbon dioxide–argon mixture for 3 minutes resulted in satisfactory stunning. However, bleeding should commence within 15 seconds to avoid resumption of consciousness. A 5 minutes exposure to these gas mixtures followed by bleeding within 45 seconds prevented carcass convulsions during bleeding. The exposure of pigs to argon-induced anoxia or the carbon dioxide–argon mixture for 7 minutes resulted in death in the majority of pigs. Owing to the prolonged exposure time required to kill pigs with anoxia, it is not used under commercial conditions. However, further research and development is needed to evaluate the feasibility of inducing unconsciousness with anoxia and then killing pigs by other means (e.g. induction of cardiac arrest in unconscious pigs using an electric current).

Carbon dioxide and argon are heavier than air and could therefore be contained within a pit. Carbon dioxide is cheaply and readily available as a byproduct of industries. On the other hand, argon has a low presence in the atmosphere (0.9% by volume) and its availability for commercial stunning practices might be limited. On the other hand, the relative density of N_2 is slightly lower than air concentrations and cannot be sustained within a pit at a higher concentration than 94% by volume (Dalmau et al., 2010). Nevertheless, this stability could be improved increased when nitrogen and CO_2 are combined (Dalmau et al., 2010). Gas mixtures of N_2 and up to 30% CO_2 have high stability and uniform concentrations along the pit. However, the higher the concentration of nitrogen in the gas mixture with CO_2, the lower the relative density of the mixture and, therefore, the more difficult it is to displace the oxygen from the pit.

In commercial conditions, when exposed to high concentration of CO_2, animals are loaded in groups into a cage or cradle and immersed into a concentration gradient of the gas, such that, as the cage is lowered into the well, the CO_2 concentration continues to rise until it reaches 80%–90% at the bottom of the well. The system can be operated with mechanical push gates that separate large group of pigs into groups of five or six and gently push them into the stun box, abolishing the use of electric prodders. This system has some animal welfare advantages compared with electrical stunning, as animals are stunned in groups with the minimum amount of restraint and handling stress (EFSA, 2004; Velarde et al., 2000). Entering the cradle and being lowered into the pit or moved within the tunnel do not cause aversion if the system contained atmospheric air (Velarde et al., 2007; Dalmau et al., 2010). This, together with the lower intensity of muscular contractions compared to electrical stunning, reduces the incidence of pale, soft and exudative (PSE) meat and haemorrhage (Velarde et al., 2001) and improves meat quality.

Two main systems exist, the dip lift system and the paternoster system (Fig. 10.5). Dip-lift designs have only one box in the system that can be loaded with a nominal capacity of six pigs. In this system, groups of pigs are lowered directly into maximum concentrations of carbon dioxide at the bottom of the pit (EFSA, 2004). The paternoster designs have up to seven boxes (a nominal capacity 2−6 pigs per box), rotating through the CO_2 gradient in a 3−8-m deep pit, stopping at various intervals for loading of live pigs on one side and unloading unconscious pigs on the other side for sticking (EFSA, 2004). The number of pigs per group, the time taken to reach maximum CO_2 concentrations, and total exposure times are manipulated by the individual abattoirs according to their own discretion (Atkinson et al., 2012). The space allowance in the box shall be enough to allow the animals to lie down without being stacked even at maximum permitted throughput. Overloading increases the risk of unnecessary excitement or insufficient stunning

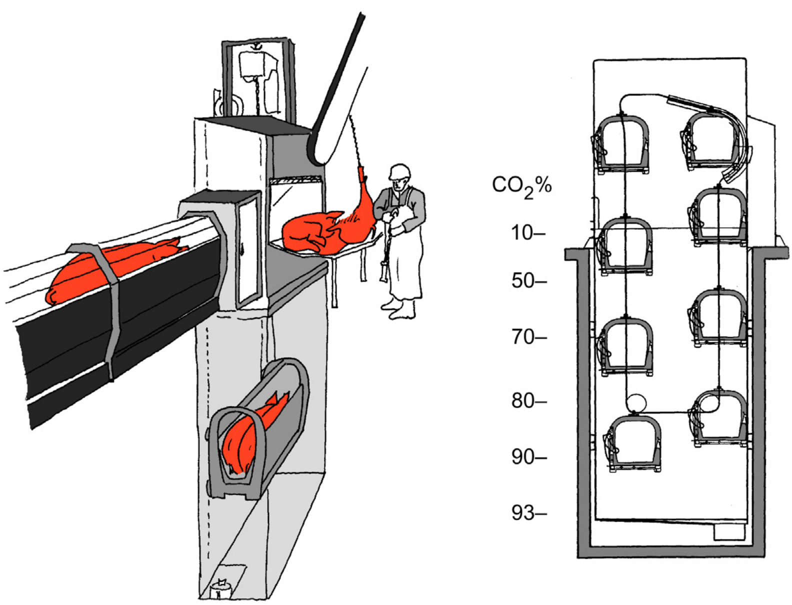

Figure 10.5 Two systems of gas stuning for pigs.

effectiveness (e.g. hiding their heads under other animals) and may lead to bruising increases. Stunning equipment shall be fitted with devices displaying and recording the gas concentration and the time of exposure and giving alarms in case of insufficient gas flow. Gases should enter into the chamber or the location where animals are to be stunned and killed in a way that it does not create burns or excitement by freezing or lack of humidity. Moreover, the control of temperature and humidity of the gas mixture could improve the welfare of the animals. Inhalation of warm and humidified air helps them to alleviate physical discomfort and distress. Moreover, because animals exposed to carbon dioxide gas also show gasping (oral breathing), it is thought that administration of a warm and humidified gas mixture will help to reduce the severity of distress.

Pig stunning with a high concentration of CO_2 can be reversible (or simple) or irreversible. The depth and duration of unconsciousness achieved with CO_2 gas stunning depends upon the animal, the CO_2 concentration, the speed at which animals are lowered towards the bottom of the pit, where the highest CO_2 concentration is achieved, and the duration of exposure (Raj and Gregory, 1996; Troeger and Woltersdorf, 1991). Due to individual biological variation, some pigs may regain consciousness while others not, even if stunned in the same group (Forslid, 1987; Holst, 2001). Exposure to high concentrations of CO_2 shortens the period of time to unconsciousness and helps to reduce the duration of hyperventilation and potential distress (Troeger and Woltersdorf, 1991; Raj and Gregory, 1996; Barton-Gade, 1999). However, the degree of aversion depends on the carbon dioxide concentration. Velarde et al. (2007) reported that the aversion was higher when the stunning system contained 90% as opposed to 70% carbon dioxide, possibly due to the increased irritation of the nasal mucosal membranes and more severe hyperventilation. Conversely, a decrease in the concentration of carbon dioxide increased the time to onset of unconsciousness as determined using time to loss of posture and, therefore, lengthened the perception of the aversive stimulus till the animal lost consciousness. Immersion of pigs into 80%−90% CO_2 usually leads to the induction of unconsciousness within 30 seconds.

To ensure good animal welfare, the stun should ensure unconsciousness is induced for a sufficient duration to include not only the stun-to-stick interval but also the time taken for brain death to occur due to sticking. Because the effect of a stunning method is momentary, the onus of preventing resumption of consciousness following stunning relies on the efficiency of the slaughter procedure, i.e. the prompt and accurate severance of blood vessels supplying oxygenated blood to the brain. Therefore, sticking must start as soon as possible after stunning to prevent resumption of consciousness. If not possible, the stun-to-stick interval can be increased proportionally without animals recovering consciousness, through increased exposure time to the gas (Holst, 2001). Prolonged exposure may result in irreversible stunning, and eliminate the chances of recovery of consciousness. Exposure of pigs to a minimum of 90% by volume of carbon dioxide in air for 3−5 minutes results in death in the majority of pigs, which can be recognised by the presence of dilated pupils and absence of gagging (rudimentary respiratory activity) at the exit from the gas.

As the duration of unconsciousness determine the maximum acceptable stun-to-stick interval, it is therefore imperative for animal welfare that unconsciousness is closely monitored, and animals restunned with a backup method (electrical or captive bolt stunning) when necessary. The recommended animal based indicators (EFSA, 2013b) for monitoring after stunning and during shackling and hoisting are muscle tone, breathing and the corneal or palpebral reflexes (Fig. 10.6). Effective gas stunning (Toolbox 4) induces collapse and loss of posture, apnoea (absence of breathing) and abolition of corneal or palpebral reflex. If the exposure to carbon dioxide is ineffective/inadequate, the animal will show attempts to regain posture and/or sustained/presence of breathing, including laboured breathing. Pigs that are not effectively stunned or those recovering consciousness will also show positive corneal or palpebral reflex. Vocalisation is expected only in conscious animals. However, not all conscious animals will vocalise, and hence absence of vocalisation does not always mean that the animal is unconscious. For monitoring at sticking (Toolbox 5), the recommended indicators to be used are muscle tone, breathing and vocalisations. An unconscious pig at this stage will loss muscle tone, hanging flaccidly on the overhead shackle or lying relaxed on the conveyor and is therefore not expected to show any changes in its posture. Loss of muscle tone can be recognised from floppy ears and relaxed jaw and completely relaxed body. In contrast, a pig recovering consciousness will attempt to regain posture, which will be manifested as righting reflex (e.g. severe kicking, head lifting, body arching), arching of the neck, body stiff (upright) ears and jaws, and/or convulsions. These signs are more visible when the animals are hanging from the overhead rail. During sticking, unconscious pigs will continue to manifest apnoea. Pigs may show gagging, that is considered a rudimentary brain stem function indicative of a dying brain in pigs. However, in association with resuscitation processes that might occur during handling, shackling and hoisting, gasping could lead to recovery of consciousness, especially if exsanguination is delayed. Pig recovering consciousness whilst hanging on the overhead shackle will attempt to breathe, which may begin as regular gagging before leading to resumption of breathing. Additionally, the corneal or palpebral reflex and response to nose prick or ear pinch may be used. For monitoring during bleeding after carbon dioxide stunning (Toolbox 6), the recommended indicators are muscle tone and breathing. The presence of righting reflex would indicate recovery of consciousness. Additionally, the corneal or palpebral reflex and vocalisations may be used. Pigs showing these signs of ineffective stunning will require immediate restun using a backup method (electrical or captive bolt stunning).

10.7 Monitoring welfare at the slaughterhouse according to Welfare Quality

Animal welfare must be approached as a multidimensional concept, and even in the slaughterhouse a set of measures assessing different areas and processes must be taken into account and not just assessing the stunning effectiveness. A good

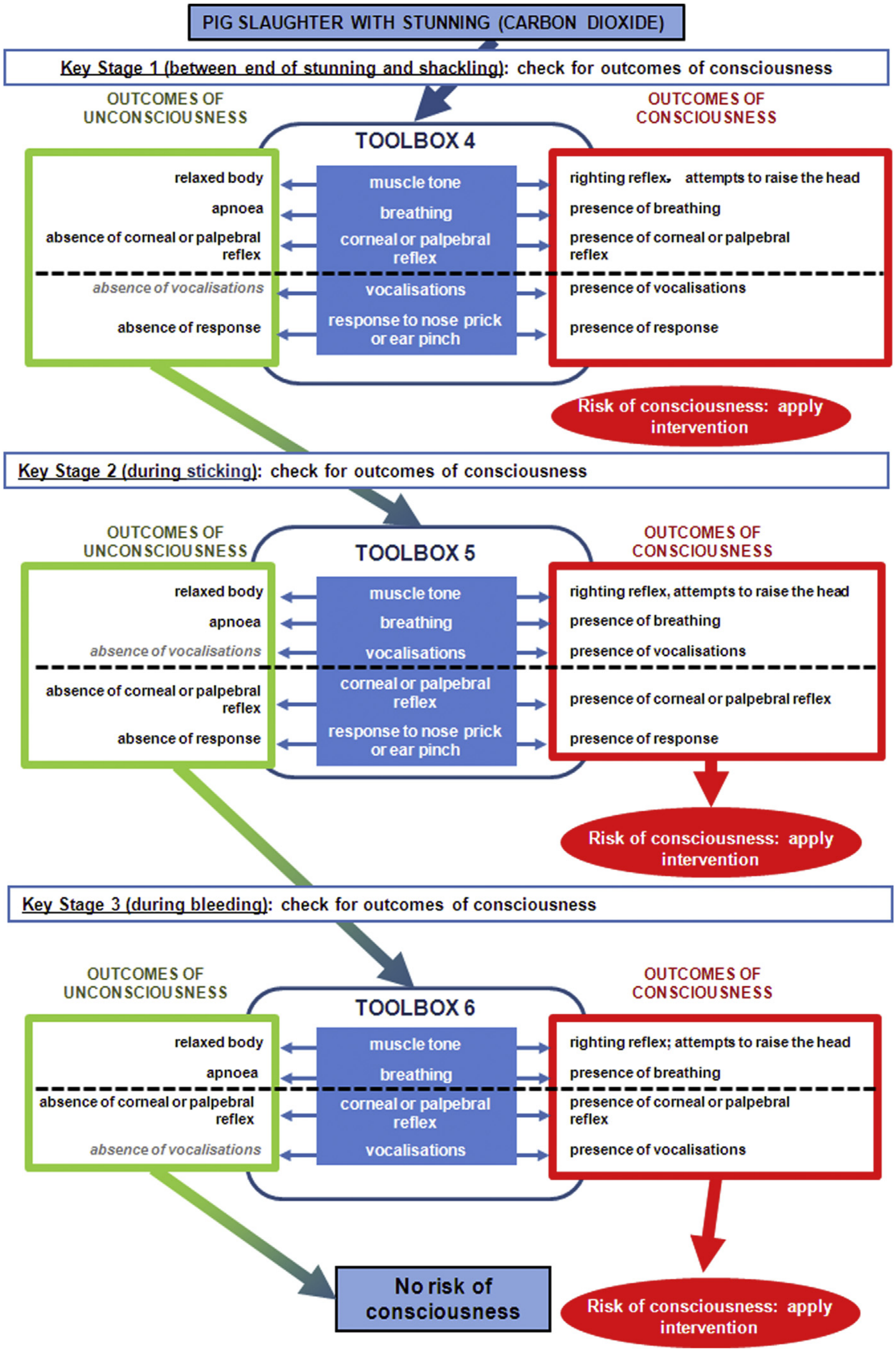

Figure 10.6 Toolbox for monitoring welfare at slaughter of pigs following carbon dioxide stunning. (The indicators below the dashed line are also proposed, but their sensitivity or feasibility is lower and they should not be relied upon solely.)

example of a complete protocol on animal welfare to be used at slaughterhouse is those published in the scope of the European project called Welfare Quality (Welfare Quality, 2009; Velarde and Dalmau, 2012).

10.7.1 Unloading assessment

Best practices during the reception of the animals at the abattoir are also described in Faucitano and Goumon, Chapter 9. In the WQ protocol, the welfare assessment starts in the unloading area, where general fear, thermoregulation behaviours, slipping and falling, sickness and dead animals are measured. The unloading area covers the ramp of the truck and the unloading bay. When the slaughterhouse does not have ramp, the unloading area extends from the beginning of the truck ramp to the end of the floor slope. If the truck has a tail gate lift, the assessment starts when the lift is on the floor and its doors are opened. In each slaughterhouse, the animals unloaded from six lorries are assessed. In two lorries, the percentage of animals that slip and fall are recorded. Slipping is defined as loss of balance without the body touching the floor, while falling is defined as loss of balance in which a part of the body other than the legs is in contact with the floor. An animal slipping while it is falling is considered only as falling. During the unloading of two other lorries, the number of animals that show general fear is assessed by means of reluctance to move and turning back behaviour. A pig shows reluctance to move when it stops walking, moving the body and the head for at least 2 seconds. Turning back occurs when the pig that is facing the unloading area, turns its body and faces the truck. Animals that turn back on arrival at the end of the unloading area are not considered. In all cases, animals unable to move by themselves are not included in the fear and slipping or falling assessment. The number of lame animals is assessed in two unloaded lorries when they are moved to the lairage pens. The gait of the animals is scored when walking between 3 and 10 m after the unloading area, according to a three point scale: 0, normal gait; 1, difficulties walking, but still using all legs (lameness-1); and 2, severely lame, minimum weight-bearing on affected limb (lameness-2). Animals that are unable to move by themselves are considered sick animals. Lameness is not assessed when the length of the corridor is less than 3 m. The number of sick and dead animals, and number of animals shivering or panting are measured in the six lorries assessed in the protocol. Shivering is defined as slow and irregular vibration of any body part or the body as a whole. Thermal panting begins through the nose, and if prolonged, it continues as rapid open-mouthed breathing with short gasps and a lot of salivation. In addition, the length, width and height of the six lorries and the total number of animals in the lorries are also considered. The presence of bedding material on the vehicle floor is also taken into account.

10.7.2 Lairage assessment

In lairage, the number of drinking points in a sampling of pens (in the case of drinking valves) or the total surface area of water supplied (in the case of water troughs) per animal, their functionality and cleanliness is assessed. In addition, the availability of feed for animals that have been held more than 12 hours in the holding pens is also evaluated. Other measures assessed in lairage are behavioural thermoregulation measures, such as huddling, shivering or panting. In this case they are scored by using a three point scale: 0, no pigs in the pen showing shivering, panting or huddling; 1, up to 20% of pigs in the pen with the above behaviour; and 2, more than 20% of pigs in the pen with the above behaviour. Shivering and panting are defined in the same way as in the unloading area and huddling is described as a pig lying with more than 50% of its body in contact with another pig, or lying some part on top of another pig. Finally, the mortality rates in lairage and space allowance are also considered. For this purpose, the length and width of the eight pens are measured and the number of animals counted.

From lairage to stunning another important stage at which welfare can be compromised is during the movement from the lairage pen to the stunning area. Most of the time, animals are forced to move quickly in the last metres prior to stunning to maintain the chain speed. Vocalisation is associated with electric prod use, excessive pressure from a restraint device, stunning problems or slipping on the floor. In the Welfare Quality protocol it is considered that this management is a problem of human–animal relationship and it is assessed by means of high pitched vocalisations (HPV), defined as squealing or screaming, at group level when pigs are moved from lairage to the stunning area. It is noted if any animal in the corridor from lairage to the stunning system displays HPV. Two types of measures are taken. The first one, named one–zero sampling, consists of assessing if any animal is showing any vocalisation during a period of 20 seconds. The second one, named instantaneous sampling, consists of assessing if any animal is showing any vocalisation just at the twentieth second of each period. Furthermore, the number of pigs that vocalised, considered as single (only one) and multi (more than one) is also recorded during the instantaneous sampling. That is repeated three times for 4 minutes each.

10.7.3 Stunning effectiveness and carcass assessment

Logically, another point to consider is the stunning effectiveness. The effectiveness of the stunning includes immediate loss of consciousness, and prolongation of this until the animal's death. The absence of corneal reflex, rhythmic breathing (as indicated by the movements of the flanks), righting reflex and vocalisations are used to assess stunning effectiveness. Stunning effectiveness is assessed immediately after stunning and immediately before sticking in 60 pigs per slaughterhouse divided into three batches of 20 pigs.

Skin lesions provide valuable information regarding the management of animals on the farm of origin, transport or in the lairage pens. Therefore, skin lesions are also assessed in the carcass of 60 animals divided into three batches of 20 animals. The carcass is divided into five parts and only one side is assessed: (1) ears, (2) front (from the head to the back of the shoulder), (3) middle (from the back of the shoulder to the hind-quarters), (4) hindquarters and (5) legs (from the accessory digit upwards). Each part is scored as follows: 0, no visible skin damage, only one lesion greater than 2 cm or lesions smaller than 2 cm; 1, between two and 10 lesions greater than 2 cm; 2, any wound which penetrates the muscle tissue, or more than 10 lesions greater than 2 cm. The scoring of the five parts of the carcass is combined in one scoring: 0, all body parts with a score of zero; 1, at least one body part with a score of one; 2, a body part with a score of two. Furthermore, the health status of the animals in the farm of origin is also assessed after slaughter (Temple et al., Chapter 12: On-farm and post-mortem pig health status assessment). The presence of pleurisy and pneumonia in the lungs, pericarditis in the heart and white spots in the liver is inspected in 60 animals divided into three batches of 20.

10.7.4 Utilisation of the WQ assessment

The Welfare Quality assessment system can be used for two main purposes. First, it can provide slaughterhouse managers with a broad picture of the welfare status of their animals as well as identifying specific aspects requiring their attention. The different measures are combined to calculate the score of each criterion independently in this case. This evaluation should serve to identify welfare problems and to advise the producer on improvement strategies in each one of the criteria. Second, the data obtained from the criteria could be combined into an overall assessment through a hierarchical evaluation model, integrating the data to an overall scoring of the slaughterhouse. At the end of the process, the slaughterhouse can be categorised according to the assessed level of welfare of their animals. In this way, the welfare assessment could be converted into an accessible and understandable information system to help stakeholders' to certify slaughterhouses and specify their markets.

10.8 Depopulation killing methods

'Depopulation' is defined in Regulation (CE) No. 1099/2009 of 24 September 2009 as the process of killing animals for public health, animal health, animal welfare or environmental reasons under the supervision of the competent authority. Killing conditions differ from regular slaughter for human consumption as it is performed on farms with minimum or no handling and restraining facilities. Furthermore, depopulation is usually performed under time pressure and especially sometimes when it concerns highly infectious or zoonotic diseases, the required speed of action and safety measures requires good planning, good communication, skilled personnel and accurate monitoring procedures (Gerritzen, 2008). The main methods used for depopulation of pigs include penetrative captive bolt stunning, free bullet, a percussive blow to the head in neonates and lethal injection.

10.8.1 Penetrative captive bolt

Penetrative captive bolt guns are designed to fire a retractable steel bolt that penetrates the cranium and enters the brain. It induces immediate loss of consciousness as the impact of the bolt on the skull results in brain concussion (EFSA, 2004). The unconsciousness is prolonged by the structural damage to the brain caused by penetration of the bolt, which results in marked subarachnoid and intraventricular haemorrhages, especially adjacent to the entry wound and at the base of the brain. While the substantial damage sustained by vital centres in the caudal regions of the brain including the brain stem rapidly renders the animal unconscious, it is the major haemorrhages caused by rupture of the arteries supplying the brain that ensures a long-lasting unconsciousness. Captive bolt stunning shall be followed as quickly as possible by procedure ensuring death such as bleeding or destruction of the brain and upper spinal cord by pithing.

Successful induction of brain concussion manifests as immediate collapse of the animal and onset of apnoea (absence of breathing), followed by the onset of a tonic seizure, which can be recognised by its head extended, hind legs rigidly flexed under the body, and fixed eyes. The fore legs may be flexed initially and then gradually straightened out. This period last for 10–20 seconds and is followed by a period of kicking movement. Ineffective or unsuccessful captive bolt stunning can be recognised by the failure to collapse, the presence of breathing (including laboured breathing) and the absence of tonic seizure; in extreme cases, animals may also vocalise.

Pigs are probably the most difficult farm animals to stun with penetrating captive bolts because the target area is very small and this can be exacerbated by the dished forehead found in certain breeds and in aged pigs (especially sows), and in comparison with other species, the brain lies deep in the head with a mass of sinuses lying between the frontal bone and the brain cavity (HSA, 2001). The ideal shooting position is in the mid-line of the forehead, 1–2 cm above eye level, and the muzzle of the captive bolt should be placed against the head and directed towards the tail (EFSA, 2004). Boars and large sows may have a ridge of bone running down the centre of the forehead. This may interfere or prevent the bolt penetrating the brain cavity and the pig will not be stunned effectively. In such cases, the recommended shooting position is 3–4 cm above the eye level and the muzzle of the captive bolt should be placed slightly to one side of the ridge, aiming into the centre of the head (HSA, 2001). However, large boars are more difficult to stun using this method as the sinuses in the forehead are well developed and the brain is laying deeper in the head than in other pigs and are preferably killed by use of a free-bullet firearm (HSA, 2001; Blackmore et al., 1995). To ensure accurate shot placement it is necessary to restrain the animal (e.g. nose snare), however this can cause further stress and agitation.

Captive bolt stunners can be used in most pigs, but it is recommended that the cartridge recommended for the equipment by the manufacturer is used (HSA, 2001), and that in all cases, captive bolt stunning should be followed by bleeding or pithing.

10.8.2 Free bullet

Free bullet is considered to be a killing method as one or more projectiles are fired into the cranium causing massive shock and brain destruction, immediate unconsciousness and consequent death. Pigs are generally shot at close range with handguns (<10 cm) or shotguns (at a distance between 5 and 25 cm). To ensure effective killing, it is recommended that animals are shot on the head, in the same position as for captive bolt, aiming to maximise damage to the structures of the brainstem (midbrain, pons and medulla). Like with captive bolt, pigs can be difficult to kill with free bullet due to the anatomy of the skull and frontal sinus, and it may be necessary to restrain the animal. In addition to the position and angulation of the shot, the projectile must have sufficient kinetic energy to ensure penetration and sufficient damage to the brain to produce instantaneous death. The calibre of firearm used depends on the age of the animal. For adult sows and boars a 12-gauge shotgun at short range is often used.

10.8.3 Percussive blow to the head

Piglets up to 5 kg live weight might be killed with manual blunt force trauma to the forehead, provoking severe damage to the brain. To be effective it must involve a single blow to the correct position on the cranium of sufficient force to produce immediate depression and severe damage of the brain. To ensure death, the percussive blow shall be followed as quickly as possible by bleeding procedure. If insufficient kinetic energy is delivered to the cranium there is the potential for incomplete concussion, which could lead to pain and distress. Compared to other methods it requires a level of skill that most stockpersons and veterinarians would be unlikely possess if they infrequently perform the procedure (Sharp et al., 2015). Therefore it is less reproducible between animals, and there is significant risk of causing incomplete concussion and suffering. Furthermore, the method is physically exhausting for personnel, and fatigue may lead to inefficient application. Therefore, it shall not be used as routine methods but only where there are no other methods available for killing.

10.8.4 Lethal injection

Lethal injections are normally anaesthetic agents administrated intravenously as an overdose for euthanasia. They can produce rapid onset of unconsciousness and death and is considered less unsightly for the public than captive bolt or free bullet. Intravenous administration of barbituric acid derivatives is effective in producing a smooth and quick irrecoverable death. They are administered at doses of between 100 and 200 mg/kg bodyweight, however it is generally advised to give 200 mg/kg. Another suitable chemical agent is T-61, a combination of an hypnotic agent (embutramide, 200 mg/mL), a curariform drug (mebezonium iodide, 50 mg/mL) and a local anaesthetic (tetracaine hydrochloride, 5 mg/mL). However, the humaneness of this has been questioned. Accidental injection of T61 outside the vein or rapid intravenous injection may cause pain and irritation. Furthermore, the neuromuscular blocking agent may induce suppression of respiration prior to the onset on unconsciousness (EFSA, 2004).

When killing livestock with chemical agents it is essential that the animal is sufficiently restrained to allow safe access to the required veins. This can either be with sedatives and/or anaesthetics (e.g. xylazine, ketamine), physical restraint or a combination of both. After delivery of the agent it is essential that the animals are monitored to ensure death.

10.9 Training in animal welfare at slaughter

Animal handling training programs have shown to be essential for a fast and effective prevention of animal suffering during pre-slaughter management and stunning. Effectiveness of training programs can be assessed by following key impacts on the participants such as changes in their attitudes, skills and behaviour as well as on the animals evaluating the progress in welfare outcomes. Several studies reported the successful application of training programs in slaughter plants. Training programs resulted in a significant reduction in the proportion of downgraded carcass due to bruising and carcass damage (Paranhos da Costa et al., 2014). Gallo et al. (2003) also reported a significant improvement in management conditions with a 47.7% reduction in the use of electric prods after slaughterhouse staff training. Training programs had also a significant effect on stunning effectiveness. In a recent study realised on 15 cattle and sheep slaughterhouse, Gallo (2010) registered a reduced incidence of animals showing signs of consciousness after stunning (4.5% to 0.5%). The generally high turnover of staff at slaughterhouses is one of the difficulties to overcome with frequent trainings.

Within the European Union and since the new Regulation (EC) No. 1099/2009 came into force, many competent authorities, official veterinarians and food business operators have encountered problems with the implementation of some requirements. Most problems relate to the quality of stunning and its assessment. For this reason, recent efforts were undertaken to provide clear recommendations on the control measures and monitoring procedures to ensure proper stunning (EFSA, 2013a). Knowledge exchange becomes an efficient tool to help implementing the legislation. In addition to slaughter plant staff, knowledge materials and training should also address other target groups such as competent authorities, official vets and animal welfare officers.

Several key points for implementation to be effective have been highlighted by the EUWelNet project (www.euwelnet.eu), such as:

- Frequent interaction and collaboration between public and private actors plays a crucial role in the early identification of knowledge gaps, the dissemination of knowledge and tailor-made information and training of target groups.
- Animal welfare has to be presented in a practical and realistic manner and the performance benefits of higher welfare have to be emphasised. Training of welfare requirements works best if the industry can see economic or other advantages to what is being requested. Target groups should understand that implementation works, how it contributes to improved welfare and how it works in practice.
- Particular care should be taken to ensure that the training material and activities are available to small-scale slaughterhouses which represent a particular target group.

- Knowledge exchange strategies should involve actively the participants promoting dialogue. Horizontal training has been particularly efficient in several training activities such as the ones undertaken by Zuin et al. (2014).
- Training has to be easily understandable and capable of crossing social constraints and language barriers.

Knowledge exchange should definitively apply worldwide through online education materials or exchange programs (Fraser, 2008). Examples of such work are given by the Humane Slaughter Association (www.hsa.org.uk) who provide training materials and opportunities in a wide range of countries. DG-SANTE organises workshops entitled *Improving animal welfare- a practical approach* (http://ec.europa.eu/food/animals/index_en.htm) and the OIE holds regional seminars for focal points (http://www.oie.int/).

10.10 Slaughter welfare legislation and codes

Slaughtering of animals is seen as a critical stage of the animal production by all stakeholders involved, including the farmers, the consumers, the meat industry, the animal welfare societies, the veterinarians and the animal welfare scientists. In the EU Council Regulation No. 1099/2009 on the protection of animals at the time of killing lays down rules to minimise avoidable pain and suffering caused to animals through the use of properly approved stunning methods, based on scientific knowledge and practical experience. Important work was recently carried out to support the implementation of the Regulation, in particular as regard the scientific elements needed for the development of monitoring procedures at slaughterhouses and for the assessment of new or modified stunning methods. The European Food Safety Authority (EFSA) provides scientific advice and technical support for the development and implementation of legislation and policies in the field of farm animal welfare. Concern over the welfare of animals is by no means restricted to Europe. Animal welfare at slaughter has been identified as a priority by the World Organisation for Animal Health (OIE), an international organisation with 184 member countries. This resulted in the OIE setting up standards for slaughter of animals and for killing of animals for disease control purposes. Furthermore, there are different private schemes for the assessment of welfare at the slaughterhouse that are connected with specific food chains or marketing food labels. Worldwide, the development of slaughter legislation and standards aims to be based on available scientific advice, taking into account public expectations, socioeconomic consequences and trade concerns.

10.11 Future trends

Nowadays, two main methods exist to stun/kill pigs: electrical and gas stunning with CO_2. Both methods might cause potential stress and aversion to the animals.

On the one hand, electrical stunning requires restraining the animal for the correct placement of the electrodes to span the brain. On the other hand, gas stunning with CO_2 does not induce immediate loss of consciousness and induction to consciousness might be aversive. Therefore, there is a need for research and development of novel stunning methods, or refinement of established ones, to achieve optimal stunning that eliminate any pain or suffering. When investigating novel stunning methods, their practicability on commercial conditions should be kept in mind.

Gas stunning has some animal welfare advantages compared with electrical stunning, as animals are stunned in groups with the minimum amount of restraint and handling stress. However, gas stunning does not induce immediate loss of consciousness, and the inhalation of the predominantly gas used nowadays (concentrations greater than 80% of CO_2 by volume in atmospheric air) causes aversion, irritation of the mucous membranes (that can be painful) and respiratory distress during the induction phase. Further research is needed to develop novel humane gas mixtures and to determine stress levels of pigs during the induction stage of gas stunning before loss of consciousness. The novel gas mixtures should be based on the induction of hypoxia, as any concentration of CO_2 seems to be aversive to the animals. Appropriate equipment should be developed and implemented under field conditions.

Although indicators of (un)consciousness, such as physical reactions and reflexes, are currently used to assess the stunning effectiveness, EFSA (2013b) stated that there is a lack of scientific publications involving simultaneous assessment of EEG indicators and these indicators. Sometimes, scientific research has not found strong correlations between an animal's brain activity and the animal's behaviour (e.g. Llonch et al., 2011, 2013). Future scientific research needs to assess the correlation between brain activity and various animal behaviours (e.g. reflexes, muscle tension) and needs to reduce the risk of false-positive and false-negative test situations so that, in the slaughterhouses, assessors and operators can assess the state of consciousness in a reliable way.

Abbreviations

AHAW	Animal Health and Animal Welfare Panel of EFSA
CPK	creatine phosphokinase
CSF	cerebrospinal fluid
DG-SANTÉ	Directorate-General for Health and Food Safety
ECoG	electrocorticography
EEG	electroencephalography
EFSA	European Food Safety Authority
HAS	Humane Slaughter Association
OIE	World Organisation for Animal Health
PSE	pale, soft and exudative meat
WQ	Welfare Quality

References

Aaslying, M.D., Barton Gade, P., 2001. Low stress pre-slaughter handling effect of lairage time on the meat quality of pork. Meat Sci. 57, 87–92.

Anil, M.H., 1991. Studies on the return of physical reflexes in pigs following electrical stunning. Meat Sci. 30, 13–21.

Atkinson, S., Velarde, A., Llonch, P., Algers, B., 2012. Assessing pig welfare at stunning in Swedish commercial abattoirs using CO_2 group-stun methods. Anim. Welf. 21, 487–495.

Barton-Gade, P.A., 1999. Preliminary observations of pig behaviour on immersion in high concentration of CO_2 gas. In: Proceedings of the International Workshop on Stunning Systems for Pigs and Animal Welfare. 25–27 August 1999, Billund, Denmark.

Bateman, D.E., 2001. Neurological assessment of coma. J. Neurol. Neurosurg. Psychiatry 71, i13–i17.

Blackmore, D.K., Bowling, M.C., Madié, P., Nutman, A., Barnes, G.R.G., Davis, A.S., Donoghus, M., Kirk, E.J., 1995. The use of shotgun for the emergency slaughter or euthanasia of large mature pigs. N. Z. Vet. J. 43, 134–137.

Brown, R.E., Basheer, R., McKenna, J.T., Strecker, R.E., McCarley, R.W., 2012. Control of sleep and wakefulness. Physiol. Rev. 92, 1087–1187.

Brown, S.N., Knowles, T.G., Edwards, J.E., Warriss, P.D., 1999. Relationship between food deprivation before transport and aggression in pigs held in lairage before slaughter. Vet. Rec. 145, 630–634.

Cook, C.J., Devine, C.E., Tavener, A., Gilbert, K.V., 1992. Contribution of amino acid transmitters to epileptiform activity and reflex suppression in electrically head stunned sheep. Res. Vet. Sci. 52, 48–56.

Croft, P.G., 1952. Problem of electrical stunning. Vet. Rec. 64, 255–258.

Dalmau, A., Llonch, P., Rodríguez, P., Ruíz-de-la-Torre, J.L., Manteca, X., Velarde, A., 2010. Stunning pigs with different gas mixtures. Part 1: gas stability. Anim. Welf. 19, 315–323.

EFSA, 2004. Welfare Aspects of Animal Stunning and Killing Methods. EFSA, Parma, Italy, 241 pp.

EFSA, 2013a. Guidance on the assessment criteria for studies evaluating the effectiveness of stunning methods regarding animal protection at the time of killing. EFSA J. 11, 3486, 41 pp. doi:10.2903/j.efsa.2013.3486.

EFSA, 2013b. Scientific opinion on monitoring procedures at slaughterhouses for pigs. EFSA Panel on Animal Health and Welfare (AHAW). EFSA J. 11, 3523.

Faucitano, L., Geverink, N.A., 2008. Effects of preslaughter handling on stress response and meat quality in pigs. In: Faucitano, L., Schaefer, A.L. (Eds.), The Welfare of Pigs: From Birth to Slaughter. Wageningen Academic Publication, Wageningen, The Netherlands, pp. 197–224.

Faucitano, L., Goumon, S., 2017. Transport of pigs to slaughter and associated handling. In: Špinka, M. (Ed.), Advances in Pig Welfare. Woodhead Publishing, Duxford, UK.

Forslid, A., 1987. Transient neocortical, hippocampal and amygdaloid EEG silence induced by one-minute inhalation of high concentration carbon dioxide in swine. Acta Physiol. Scand. 130, 1–10.

Fraser, D., 2008. Toward a global perspective on farm animal welfare. Appl. Anim. Behav. Sci. 113, 330–339.

Gallo, C., 2010. Diagnóstico e implementación de estrategias de bienestar animal para incrementar la calidad de la carne de rumiantes, financiado por la Fundación para la

Innovación Agraria (FIA-Chile) y la Asociación Gremial de Plantas Faenadoras y Frigoríficos de Carne (FAENACAR-Chile), 2005–2010.
Gallo, C., Teuber, C., Cartes, M., Uribe, H., Grandin, T., 2003. Mejores en la insensibilizacion de bovinos con pistol pneumatica de propectil retenido tras cambios de equipomiento y capacitacim del personal. Arch. Med. Vet. 35, 159–170.
Gerritzen, M., 2008. Killing for disease control purposes-can welfare be assured? In: Animal Welfare at Slaughter and Killing for Disease Control—Emerging Issues and Good Examples. 1–3 October 2008, Hindåsgården, Sweden, pp. 53–59.
Geverink, N.A., Engel, B., Lambooij, E., Wiegant, V.M., 1996. Observations on behaviour and skin damage of slaughter pigs and treatment during lairage. Appl. Anim. Behav. Sci. 50, 1–13.
Grandin, T., 1997. Assessment of stress during handling and transport. J. Anim. Sci. 75, 249–257.
Gregory, N.G., 1998. Stunning and slaughter. In: Gregory, N.G. (Ed.), Animal Welfare and Meat Science. CAB International, Oxon, UK.
Hoenderken, R., 1978. Elektrische bedwelming van slachtvarkens (Electrical stunning of slaughter pigs). Doctoral Dissertation, University of Utrecht, The Netherlands.
Holst, S., 2001. Carbon dioxide stunning of pigs for slaughter: practical guidelines for good animal welfare. In: Proceedings of the 47th International Congress of Meat Science and Technology, vol. I. Krakow, Poland, pp. 48–54.
Honkavaara, M., 1989. Influence of lairage on blood composition of pig and on the development of PSE pork. J. Agric. Sci. Finl. 61, 433–440.
HSA (Humane Slaughter Association), 2001. Captive-Bolt Stunning of Livestock. Guidance Notes No. 2. third ed. Humane Slaughter Association, Hertfordshire, UK.
Huang, Q.F., Gebrewold, A., Zhang, A., Altura, B.T., Altura, B.M., 1994. Role of excitatory amino acid in regulation of rat pial microvasculature. Am. J. Physiol. 266, R158–R163.
Kanitz, E., Otten, W., Tuchscherer, W.O.M., 2005. Centraland peripheraleffects of repeated noise stress on hypothalamic_pituitary_adrenocorticalaxis in pigs. Livest. Prod. Sci. 94, 213–224.
Laureys, S., Owen, A.M., Schiff, N.D., 2004. Brain function in coma, vegetative state, and related disorders. Lancet Neurol. 3, 537–546.
Llonch, P., Andaluz, A., Rodríguez, P., Dalmau, A., Jensen, E.W., Manteca, X., Velarde, A., et al., 2011. Assessment of consciousness during propofol anaesthesia in pigs. Vet. Rec. 169, 496.
Llonch, P., Rodríguez, P., Jospin, M., Dalmau, A., Manteca, X., Velarde, A., 2013. Assessment of unconsciousness in pigs during exposure to nitrogen and carbon dioxide mixtures. Animal 7, 492–498.
Munk, M.H.J., Roelfsema, P.R., Konig, P., Engel, A.K., Singer, W., 1996. Role of reticular activation in the modulation of intracortical synchronization. Science 272, 271–274.
OIE, 2009. Slaughter of Animals, Terrestrial Animal Health Code eighteenth ed. World Organisation for Animal Health, Paris, France.
Paranhos da Costa, M.J.R., Huertas, S.M., Strappini, A.C., Gallo, C., 2014. In: Grandin, T. (Ed.), Handling of Transport of Cattle and Pigs in South America. Livestock Handling and Transport—CABI, Wallingford, UK.
Parvizi, J., Damasio, A., 2001. Consciousness and the brainstem. Cognition 79, 135–159.
Pérez, M.P., Palacio, J., Santolaria, M.P., Aceña, M.C., Chacón, G., Verde, M.T., Calvo, J.H., Zaragoza, P., Gascón, M., Garcia-Belengué, S., 2002. Influence of lairage time on some welfare and meat quality parameters in pigs. Vet. Res. 33, 239–250.

Raj, A.B.M., Gregory, N.G., 1995. Welfare implications of the gas stunning of pigs. 1. Determination of aversion to the initial inhalation of carbon dioxide or argon. Anim. Welf. 4, 273–280.

Raj, A.B.M., Gregory, N.G., 1996. Welfare implications of the gas stunning of pigs Stress of induction of anaesthesia. Anim. Welf. 5, 71–78.

Raj, A.B.M., Johnson, S.P., Wotton, S.B., McInstry, J.L., 1997. Welfare implications of gas stunning of pigs. 3. Time to loss of somatosensory evoked potentials and spontaneous electrocorticogram of pigs during exposure to gases. Br. Vet. J. 153, 329–340.

Regulation (EC) No. 1099/2009 of 24 September 2009 on the protection of animals at the time of killing.

Rosen, A.S., Morris, M.E., 1991. Depolarising effects of anoxia on pyramidal cells of rat neocortex. Neurosci. Lett. 124, 169–173.

Santos, C., Almeida, J.M., Matias, E.C., Fraqueza, M.T., Rosaro, C., Sardina, L., 1997. Influence of lairage environmental conditions and resting time on meat quality in pigs. Meat Sci. 45, 253–262.

Sharp, T.M., McLeod, S.R., Leggett, K.E.A., Gibson, T.J., 2015. Evaluation of a spring-powered captive bolt gun for killing kangaroo pouch young. Wildl. Res. 41, 623–632.

Talling, J.C., Waran, N.K., Wathes, C.M., Lines, J.A., 1996. Behavioural and physiological responses of pigs to sound. Appl. Anim. Behav. Sci. 48, 187–202.

Temple, D., Llonch, P., Mainau, E., Manteca, X., 2017. On-farm and post-mortem pig health status assessment. In: Špinka,, M. (Ed.), Advances in Pig Welfare. Woodhead Publishing, Duxford, UK.

Troeger, K., Woltersdorf, W., 1991. Gas anaesthesia of slaughter pigs. Stunning experiments under laboratory conditions with fat pigs of known halothane reaction type: meat quality and animal protection. Fleischwirtschaft 71, 1063–1068.

Van de Perre, V., Ceustermans, A., Leyten, J., Geers, R., 2010. The prevalence of PSE characteristics in pork and cooked ham—Effects of season and lairage time. Meat Sci. 86, 931–937.

Velarde, A., Dalmau, A., 2012. Animal welfare assessment at slaughter in Europe: moving from inputs to outputs. Meat Sci. 92, 244–251.

Velarde, A., Ruiz-de- la-Torre, L., Stub, C., Diestre, A., Manteca, X., 2000. Factors affecting the effectiveness of head-only electrical stunning in sheep. Vet. Rec. 147, 40–43.

Velarde, A., Gispert, M., Faucitano, L., Alonso, P., Manteca, X., Diestre, A., 2001. Effects of the stunning procedure and the halothane genotype on meat quality and incidence of haemorrhages in pigs. Meat Sci. 58, 313–319.

Velarde, A., Cruz, J., Gispert, M., Carrión, D., Ruiz-de-la-Torre, J.L., Diestre, A., Manteca, X., 2007. Aversion to carbon dioxide stunning in pigs: effect of the carbon dioxide concentration and the halothane genotype. Anim. Welf. 16, 513–522.

Von Mickwitz, G., Heer, A., Demmler, T., Rehder, H., Seidler, M., 1989. Slaughter of cattle, swine and sheep according to the regulations on animal welfare and disease control using an electric stunning facility. (SCHERMER, Type EC) Dtsch. Tierarztl. Wschr. 96, 127–133.

Warriss, P.D., 1994. Ante mortem handling of pigs. In: Cole, D.J.A., Wiseman, J., Varley, M.A. (Eds.), Principles of Pig Science. Nothingam University Press, Loughborough, UK, pp. 425–432.

Warriss, P.D., Wilkins, L.J., 1987. Exsanguination in meat animals. In: Preslaughter Stunning of Food Animals. Proceedings of a Seminar Organised by the European Conference Group on the Protection of Farm Animals. Brussels, Belgium, pp. 150–158.

Warriss, P.D., Brown, S.N., Edwards, J.E., Anil, M.H., Fordham, D.P., 1992. Time in lairage needed by pigs to recover from the stress of transport. Vet. Rec. 131, 194–196.

Weeks, C.A., 2008. A review of welfare in cattle, sheep, and pig lairages, with emphasis on stocking rates, ventilation and noise. Anim. Welf. 17, 275–284.

Weeks, C.A., Brown, S.N., Lane, S., Heasman, L., Benson, T., Warriss, P.D., 2009. Noise levels in lairages for cattle, sheep, and pigs in abattoirs in England and Wales. Vet. Rec. 165, 308–314.

Welfare Quality, 2009. Welfare Quality Assessment Protocol for Pigs (Sows and Piglets, Growing and Finishing Pigs). Welfare Quality Consortium, Lelystad, Netherlands.

Woodbury, D.M., Karler, R., 1960. The role of carbon dioxide in the nervous system. J. Am. Soc. Anaesthesiol. 21, 686–703.

Wotton, S.B., Gregory, N.G., 1986. Pig slaughtering procedures: time to loss of brain responsiveness after exsanguination or cardiac arrest. Res. Vet. Sci. 40, 148–151.

Zuin, L.F.S., Zuin, P.B., Monzon, A.G., Paranhos da Costa, M.J.R., Oliveira, I.R., 2014. The multiple perspectives in a dialogical continued education course on animal welfare: accounts of a team of extension agents and a manager and a cowboy from a rural Brazilian territor. Linguist. Educ. 28, 17–27.

Pain in pigs: Characterisation, mechanisms and indicators

11

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11.1 Introduction

Dating back over two hundred years, the English philosopher Jeremy Bentham was among the early advocates for animal rights, and is often quoted for raising the question "Can they suffer?" (Bentham, 1789) as part of a discussion of animal sentience. Despite this long history of debate about negative affective states in animals, it was only in the last decades of the twentieth century, that the state of pain was mentioned in definitions of animal welfare (The Five Freedoms published by FAWC, 1979), included in veterinary education (Rollin, 1989), and became target of scientific interest (Bateson, 1991; Molony and Kent, 1997).

Despite thousands of years of domestication (Giuffra et al., 2000), the pig is among the least examined of the mammalian species held by man, in terms of knowledge of causes and indicators of pain, which remain a challenge for the veterinary profession (Viñuela-Fernandez et al., 2007). Even today, it is striking to see how little the pig is represented in veterinary textbooks on pain management (Gaynor and Muir, 2015; Egger et al., 2014). Knowing that throughout the world, human consumption of pork exceeds all other meat products (FAO, 2009), combined with the fact that the pig is considered an advantageous animal model for various human conditions, and is used extensively in biomedical research (Swindle and Smith, 2015; Marchant-Forde and Herskin, Chapter 16: Pigs as laboratory animals), this lack of knowledge may seem paradoxical. Based on the available knowledge about porcine neuroanatomy, physiology and studies focusing on pig behaviour and pathology, as well as biomedical studies of humans and rodent models, this chapter reviews evidence for causes of pain in pigs and the possibility for quantification of indicators of pain states. In the chapter, we focus on the large meat producing breeds, and include smaller breeds when relevant.

11.2 Definition of pain

Ultimately, pain is a perceptional phenomenon. It is built from information gathered by specialised sensory receptors for tissue damage, modified by ascending and descending spinal and supraspinal mechanisms, and integrated into a discrete sensory experience with a negative emotional valence in the brain. Pain can be defined as

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'An unpleasant sensory and emotional experience associated with actual or potential tissue damage, or described in terms of such damage' (Meskey and Bogduk, 1994). Despite the challenges posed by nonverbal individuals, such as animals, this definition was deliberately formulated to include nonhuman animals, by the specification of 'the inability to communicate verbally does not negate the possibility that an individual is experiencing pain and is in need of appropriate pain-relieving treatment'. Previously, animal pain was defined specifically, for instance by formulation of criteria (Bateson, 1991) or described in terms of behavioural actions of the animals (Molony et al., 1995). Recently, Sneddon et al. (2014) suggested that a list of criteria should be used in a definition of animal pain. However, this chapter is based on the above pain definition – covering humans as well as animals – formulated by the International Association for the Study of Pain (IASP) (Meskey and Bogduk, 1994) and emphasising pain as a complex phenomenon, with sensory, cognitive and affective components.

As reviewed by Viñuela-Fernández et al. (2007), unmitigated pain is a major animal welfare concern. In humans as well as rodent models, a scientific debate has focused on the possibility for social stressors to lead to affective states sharing similarities with states induced by tissue damage (Eisenberger et al., 2003). However, based on recent evidence concluding that there may be overlap between brain regions responding to social stress and pain, but that these experiences are distinct (Iannetti et al., 2013), this chapter is limited to pain originating from tissue damage and nociceptive input. Below, we will go through central terms of relevance for the understanding of porcine pain and its welfare consequences.

Being able to avoid tissue damage is highly adaptive (Smith and Lewin, 2009). In its simplest way, the reflexive behavioural responses, this ability is widespread in the animal kingdom (as reviewed by Sneddon et al., 2014) and covers the physiological term nociception (coined by Sherrington in the early twentieth century (Sherrington, 1906)), describing a fundamental sensory system alerting an organism to potential damage by activating sensory receptors for tissue damage (nociceptors) and subsequent nervous signalling to induce avoidance. Thus, nociception as such does not imply pain perception, but distinguishes physiological processes from subjective experiences. In animals, signs of nociception may – under controlled conditions – be quantified and provide important information about the processing of nociceptive stimuli and changes therein. In pigs, methods for quantification of nociceptive responses have been developed during the last decade (Sandercock et al., 2009; Nalon et al., 2015).

The pig has sufficient cognitive and emotional capacity to experience negative affective states such as pain, and not just show reflexive avoidance behaviour in response to tissue damage. Sneddon et al. (2014) reviewed how mammals (however, only examined scientifically in few species) live up to the suggested criteria for animal pain, and underlined that stimuli that are reported as painful in humans, induce similar physiological and behavioural responses in mammalian species such as the pig (even though few studies have involved the pig as compared to other mammalian species kept by man). One critical criterion for the presence of pain in animals is the ability for analgesic drugs or anaesthetic techniques to counteract effects of a particular condition involving tissue damage (Sneddon et al., 2014; Weary et al., 2006). In pigs, a number of examples of this are available, for instance in terms of behavioural changes after castration in piglets (Keita et al., 2010) or in a model of femoral fracture (Royal et al., 2013).

11.3 Pain terminology

11.3.1 *Characterisation of pain based on duration and involvement of inflammation*

There are several suggested ways to categorise pain, typically based on the involvement of inflammation as well as the anatomical location of the tissue damage (Cervero, 2012). Table 11.1 lists important types of pain based on the involvement of inflammation. This distinction can be recognised across animal species, and is central for the understanding of the welfare consequences of animal pain.

11.3.1.1 Nociceptive pain

The nociceptive system is a submodality of the somatosensory nervous system (Figs. 11.1 and 11.2). Nociceptive pain arises from activation of nociceptors, followed by ascending nervous signalling, and functions to protect the organism from (further) injury (Meskey and Bogduk, 1994). Nociceptive pain is by definition short lasting, and typically leads to active avoidance behaviour (Sneddon et al., 2014), in pigs expressed as for example escape attempts or vocalisations (Weary et al., 1998). Wiese and Yaksh (2015) introduced the mechanisms and neurobiological

Table 11.1 Characteristics of distinct types of pain based on the duration of the pain state as well as the involvement of inflammation (Meskey and Bogduk, 1994; Cervero, 2012)

	Nociceptive pain	Inflammatory pain	Chronic pain
Description	Short-lasting pain arising from actual or threatened damage to tissue. Arises from activation of nociceptors.	More persistent pain arising from inflammatory processes at a site of tissue damage. May lead to hyperalgesia.	A pain state which persists even after healing of the initial tissue damage or where no healing is possible. May be inflammatory or not.
Biological function	To protect the organism from injury.	To protect the healing tissue.	Nonadaptive

processes underlying nociceptive pain in mammals. In pigs, a number of studies have focused on nociceptive pain states, such as the immediate behavioural response to castration (Leidig et al., 2009) or tail docking (Marchant-Forde et al., 2014) as is standard practice in commercial pig production in many countries (Valros, Chapter 5: Tail biting). In terms of animal welfare, however, nociceptive pain is probably not as critical as the other pain types (Woolf, 1995), the extent and expression of which have been investigated to a much lower degree.

11.3.1.2 Inflammatory pain

In contrast to nociceptive pain, inflammatory pain is persistent and arises from inflammatory processes at a site of tissue damage (see for example Ringkamp et al. (2013) for a review of the typical inflammatory responses) functioning to protect the healing tissue, and leading to more discrete behavioural responses than the nociceptive pain, such as inactivity or guarding behaviour (Mogil, 2009). Characteristic for inflammatory pain is that the nervous system moves to a more excitable state, which may continue for the duration of the healing process, leading to amplification of the nervous signalling from the inflamed part of the body, and to an increased risk of pain chronification in cases where the pain is not relieved (Flor and Turk, 2011). Studies of porcine inflammatory pain have focused on persistent conditions, such as pain during the hours and days after castration (Hay et al., 2003), pain in sows with decubital shoulder ulcers (Larsen et al., 2015) or the possibilities for pain relief in tail-bitten pigs (Viitasaari et al., 2015). However, even though this type of pain – due to the amplified nervous signalling and the risk of chronification – is critical in terms of animal welfare, only very limited species-specific knowledge about relations between tissue damage, the inflammatory response and potential consequences in terms of pain exist in pigs.

A classic condition observed during inflammatory pain states, which may have serious consequences in terms of animal welfare, is hyperalgesia (increased pain from a stimulus that normally provokes pain; Meskey and Bogduk, 1994), which is a result of the amplified nervous signalling and covers increased sensitivity of injured tissue caused by the local presence of inflammatory mediators, leading to sensitisation of nociceptors, and consequently to a local lowered threshold and larger response magnitude (primary hyperalgesia). The result of this 'inflammatory soup' is the excitation and increase in sensitivity of the peripheral nociceptors, which consequently become responsive to stimuli of low-intensity, and the activation of so-called silent nociceptors. In cases where nociceptor signalling reaches a high magnitude and persistence, sensitisation may develop at spinal or even supraspinal levels, leading to increased sensitivity in body areas surrounding the original tissue damage (secondary hyperalgesia) (Woolf, 2011). In pigs, studies have focused on development of methodology to document hyperalgesic states (Tapper et al., 2013; Mohling et al., 2014; Di Giminiani et al., 2015), for example in response to experimentally induced lameness (Pairis-Garcia et al., 2014), kaolin-induced inflammation in the metacarpus of one leg (Fosse et al., 2011a, 2011b) or the presence of decubital shoulder ulcers (Dahl-Pedersen et al., 2013).

11.4 Chronic pain

The term chronic pain implies a sustained pain state, characterised by some degree of irreversibility. However, in the scientific literature, this term has no agreed definition (as discussed by Meskey and Bogduk, 1994), but may comprise pain states lasting considerably longer – sometimes truly chronic – than the duration of the healing of the initial tissue damage. In these cases, it is changes in the nervous system that become the pathology, and the pain is maladaptive offering no survival advantage (Woolf and Doubell, 1994). For reasons that are still not fully understood, but suggested to involve peripheral and spinal cord reorganisation (Apkarian et al., 2013), some humans develop chronic pain states after exposure to tissue damage and concurrent short-term pain (Ossipov et al.,2014). However, the term chronic pain is also covering pathological conditions (for example certain locomotive disorders such as osteochondrosis (Ytrehus et al., 2007), which is common in pigs in production systems (van Grevenhof et al., 2011), where no healing takes place, or where the severity may even be increasing over time due to tissue degeneration (McCoy et al., 2013). Common to both types of conditions is that the concurrent chronic pain may involve pain states such as (episodic) nonevoked pain and hyperalgesia. Hence, the term chronic pain does not imply that the pain as such is constant. In humans, chronic pain has massive implications for the quality of life of patients and affects a significant proportion of the population (Tsang et al., 2008). Consequently, in recent years, biomedical research has targeted examination of risk factors for the development of chronic pain as well as improved treatment (Flor and Turk, 2011). A number of animal models for chronic pain exist (Gregory et al., 2013), but only very little is known about chronic pain states in farm animals such as the pig, despite the obvious potential consequences in terms of animal welfare, and despite the fact that data from slaughterhouses and culled animals document high prevalence of pathological conditions potentially leading to chronic pain (such as locomotive disorders (Kirk et al., 2005) or tail lesions (Harley et al., 2012).

11.4.1 Characterisation of pain based on the anatomical location of the tissue damage

Irrespective of the state of pain, the anatomical location of the involved tissue damage implies some typical characteristics, such as how the pain is experienced and expressed, which may be important for the consequences of the pain in terms of animal welfare. Anatomically, the body can be split into soma (skin, muscles, joints, bones), viscera (inner organs including testes and udder) and nervous system/brain. Below, we will describe characteristics of these three types of pain and their relevance for porcine welfare.

11.4.1.1 Somatic pain

The term somatic pain covers pain from damaged skin, joints, bones or muscles. In humans as well as animals, this type of pain is by far the best described, and known to be relatively easy to localise for patients, making the identification of these pain states easier for observers as well. Somatic pain has been studied in pigs, e.g. as a consequence of experimental surgery (Lykkegaard et al., 2005), experimentally induced lameness in sows (Mohling et al., 2014) or naturally occurring lameness in piglets (Meijer et al., 2015). However, in light of the relatively high prevalence of somatic injuries reported from pigs in production systems (e.g. skin lesions in group-housed sows (Kilbride et al., 2009)), as well as the increasing number of studies, where the pig is used in survival studies and subjected to experimental somatic tissue damage (e.g. in skin burn models (Sheu et al., 2014)), the knowledge about relations between involved tissue types, severity of the tissue damage and the involved somatic pain is limited. This lack of knowledge may underlie the remarkably low reporting of postoperative analgesia (reflecting either under-reporting or under-use) as evidenced by Bradbury et al. (2015) in a review of more than 200 papers, of which a significant proportion involved surgically induced somatic tissue damage.

11.4.1.2 Visceral pain

Visceral pain covers pain from the inner organs (including testes and udder). As described by Cervero (1999) visceral pain has five important clinical characteristics: (1) is not evoked from all viscera (as some viscera, such as liver or kidneys, are innervated by receptors that do not evoke conscious perception); (2) is not always linked to visceral injury (e.g. stretching the bladder is painful); (3) is experienced as diffuse and poorly localised; (4) is referred to other locations; and (5) is accompanied by autonomic responses such as nausea and vomiting. As a consequence of these, visceral pain is recognised as a significant threat to the quality of life in human patients (Bryant et al., 2011). Considering the high prevalence of visceral pathology, such as gastric ulcers, in slaughter pigs (Swaby and Gregory, 2012) and sows (Nielsen et al., 2013), and the obvious potential consequences of untreated visceral pain in terms of animal welfare, the lack of knowledge about porcine visceral pain is striking. At present, the available knowledge comes from studies of castration in piglets (Kluivers-Poodt et al., 2012) and a few studies of farrowing in sows (Mainau and Manteca, 2011; Viitasaari et al., 2013).

11.4.1.3 Neuropathic pain

Neuropathic pain covers pain caused by a lesion or disease of the somatosensory nervous system (Meskey and Bogduk, 1994). This type of pain is caused by maladaptive pathophysiological functions in the affected nerves, which may lead to sensory abnormalities such as unpleasant abnormal sensation (dysesthesia), hyperalgesia, and pain in response to stimuli that does not normally provoke pain (allodynia) (Woolf and Mannion, 1999). Neuropathic pain is known to have severe and long term consequences in terms of human quality of life (Jensen et al., 2007) and most probably in terms of animal welfare as well. Research has been focused on this type of pain, aiming to understand the underlying mechanisms and to develop pain relieving drugs (as reviewed by Zimmermann, 2001). Consequently, a large number of animal models of neuropathic pain exist (Jaggi et al., 2011), of which we are only aware of one involving pigs (Castel et al., 2016). The normal healing of nerve damage can be described as a self-repair response, where a damaged or transected axon will grow fine nerve processes (sprouts) and endbulbs. If no healing is possible, as for instance in cases of amputation, the endbulbs and sprouts may form traumatic neuromas (Foltán et al., 2008), characterised by a risk of hyperexcitability, abnormal pulse generation and spontaneous firing, and hence constituting the basis for potentially negative consequences in terms of welfare of the affected animals. However, traumatic neuromas may also be nonsymptomatic (van der Avoort et al., 2013). In pigs, the major focus on neuropathic injuries have been directed at consequences of tail docking, which is a common practice in many pig producing countries. Simonsen et al. (1991) described neuromas in tail stumps of slaughter pigs tail docked months earlier, and recent studies have shown that neuromas are formed irrespectively of tail docking length (Herskin et al., 2015), that neuromatous tissue formation can be observed as early as one month after tail docking, and that traumatic neuroma development and active tail stump reinnervation is still going on 16 weeks after the tail docking injury (Sandercock et al., 2016). However, it is still not clear whether these neuroanatomical changes lead to pain or changes in sensitivity of the tail stumps. Recently, neuromas were described in healed shoulders of sows formerly suffering from decubital shoulder ulcers, and a tendency for increased sensitivity towards palpation of the shoulder areas was found (Dahl-Pedersen et al., 2013). However, despite the research effort and the possibilities for neuropathic pain in modern pig production, the consequences of nerve injury in terms of porcine pain are not yet understood (see also Table 11.2).

Table 11.2 Characteristics of distinct types of pain based on the anatomical location of the tissue damage

	Somatic pain	Visceral pain	Neuropathic pain
Description	Pain arising from damaged skin, joints bones or muscles and dependent on activation of somatic afferent fibres	Pain from the inner organs (including testes and udder) and dependent on activation of visceral afferent fibres	Pain caused by a lesion or disease of the somatosensory nervous system
Characteristics	Well-described and easy to localise	Diffuse and poorly localised	Associated with sensory abnormalities (e.g. dysesthesia, hyperalgesia, and allodynia)

11.5 Anatomy and physiology of the pig pain system

11.5.1 Somatosensory system (peripheral and central nervous system)

The overall anatomy and physiology of the somatosensory system, essential to the perception of pain, is common for most mammalian species, and has not, yet, been described fully in pigs. The ability to detect and discriminate among potentially tissue damaging stimuli is strongly dependent on nociceptors, which are activated by noxious (tissue damaging) stimuli of a thermal, mechanical, chemical or electric nature. A stimulus needs to be of an intensity that reaches a specific threshold (e.g., a certain temperature or mechanical pressure). Activated sensory nerve endings transduce the noxious stimulus into an electric signal (action potential), which is transmitted to higher segments of the pain pathways (Fig. 11.1).

As a result, the signal reaches the spinal cord, where it is modulated before projection to the brain, where the pain is perceived. The involvement of several brain regions, in particular of the somatosensory cortex, is crucial to the perception and the control of pain (as discussed by Emma M. Baxter and Sandra A. Edwards in Chapter 3: Piglet mortality and morbidity: inevitable or unacceptable? for newborn piglets).

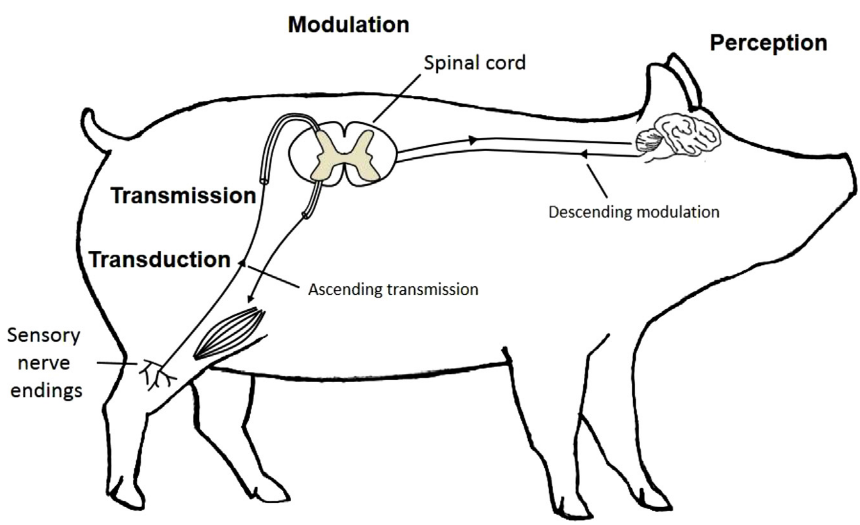

Figure 11.1 Pig pain pathway. Afferent fibres innervating e.g. skin and viscera are activated by tissue-damaging stimuli or abnormal nerve activity in the presence of e.g. injury, inflammation, and neuropathy. From peripheral afferents, information is transmitted to the spinal dorsal horn and consequently reaches the somatosensory cortex where pain perception occurs (ascending transmission). Pain transmission can be modulated by the dorsal horn of the spinal cord or by descending inhibitory mechanisms from the brain, through the release of neurotransmitters (descending modulation).
Illustration by Pierpaolo Di Giminiani.

Detection of pain sensation is dependent on two specific types of nerve fibres: myelinated Aδ- and unmyelinated C-fibres. These are found in tissue types such as skin, subcutaneous tissues, joints, muscles, bones and viscera and are responsible for the transduction of stimuli of varying intensities and sensory modalities. Aδ-fibres are responsible for the detection of low and high-threshold mechanical and thermal stimuli, and C-fibres respond to high-threshold polymodal stimuli (mechanical, thermal and chemical). The two fibre types are characterised by fast (Aδ) and slow (C) conduction velocities, determining the perception of 'first', sharp (Aδ) and 'second', dull pain (C). Furthermore, both Aδ and C-fibres encompass silent nociceptors, which can be activated by tissue damage and inflammation.

In pigs, assumptions made on the functioning of neural pain pathways are based on the high correspondence of Aδ- and C-fibres with humans (Karanth et al., 1991; Lynn et al., 1996). In addition, distribution of free sensory nerve endings, axonal excitability and conduction velocities are strongly correlated between human and porcine nociceptors (Obreja and Schmelz, 2010; Obreja et al., 2010).

The mechanisms behind peripheral and central sensitisation have primarily been investigated in humans and rodents. However, we now have access to more information about pigs, elucidating the role of different components of the pain pathways involved in inflammatory responses. In particular, one of the ion channels involved in the neurotransmission at the post-synaptic level (transient receptor potential vanilloid 1 (TRPV1)), has been characterised in pigs and found to possess molecular characteristics highly homologous with the human analogue (Ohta et al., 2005). Its role in transmission of noxious heat or sensitisation is central to the functioning of the pain response, making it a crucial target for therapeutic research (Brown et al., 2015). The mechanism of sensitisation in pigs has also been demonstrated with application of clinical models of inflammation. Irradiation of the skin with UVB-light has been observed to cause the same inflammatory response, with hyperexcitation of peripheral nociceptors, as previously observed in humans (Eisenbarth et al., 2004; Rukwied et al., 2008; Di Giminiani et al., 2014). Indeed, in a review of the use of porcine nerves as models for human pathology, Obreja and Schmelz (2013) concluded that the large degree of homology between human and porcine nerves facilitates translational approaches.

11.5.2 The HPA axis and sympathetic nervous system

The processing of pain is not an exclusive domain of the sensory system. Irrespective of the type of pain, it is stressful (as discussed by Mellor et al., 2000), thereby implying the involvement of the neuroendocrine system and the sympathetic nervous system in pain responses.

Chronic pain may even be considered a form of chronic stress (Blackburn-Munro and Blackburn-Munro, 2001), and human patients suffering from chronic pain often display disturbances of the hypothalamic−pituitary−adrenal (HPA) axis and limbic system with reported abnormal levels of cortisol (Korszun et al., 2002). In pigs, only very little work has been directed at potential chronic pain states, but several investigations have been carried out to quantify short-term changes in glucocorticoids such as cortisol and ACTH after tissue damaging procedures such as tail docking (Prunier et al., 2005; Sutherland et al., 2008, 2012) and castration (Carroll et al., 2006). Below, we describe the use of neuroendocrine pain indicators in pigs.

In parallel with the neuroendocrine system, the sympathetic adrenomedullary system, part of the autonomic nervous system (ANS), is involved in the response of the organism to stress- and painful conditions (see Nilsson, 1983 for a review of the mammalian ANS). Curiously, some of the earliest descriptions of the mammalian ANS were based on dissections of pigs, performed by Galenos (AD130–200), an anatomist and physiologist of the antiquity (Ackerknecht, 1974). The ANS has an instrumental regulatory function to maintain bodily homoeostasis, therefore adapting and adjusting the physiological conditions following any disruption, such as a painful event. The ANS contributes to the modulation of pain pathways through excitatory sympathetic or inhibitory parasympathetic mechanisms. The excitatory function implies the enhancement of the activity of Aδ- or C-fibres, whereas parasympathetic inhibition reduces the nerve fibre activity.

As reviewed by Prunier et al. (2013), sympathetic responses to pain may be quantified in farm animals directly as afferent nerve activity (Rohrbach et al., 2009) (however, requiring intensive facilities) or as catecholaminergic activity (adrenaline or noradrenaline) (Hay et al., 2003). Indirectly, the resulting autonomic changes such as heart rate, blood pressure, body and skin temperature, respiratory rate, piloerection or pupillary enlargement can be measured. In humans, changes in heart rate and blood pressure in response to painful stimuli are routinely used as surrogate markers to assess analgesia in anaesthetised patients (Bantel and Trapp, 2011). Similarly, in pigs, some direct as well as indirect measures of sympathetic nervous activity have been used as pain indicators. Below, we give examples of these studies.

11.6 Indicators of pain in pigs

In principle, we can never know the pain experienced by other individuals, and our ability to recognise pain across species is even further challenged. Based on the criteria set up by Sneddon et al. (2014), several (more or less validated) indicators of pain in pigs exist (see Table 11.3). It is, however, important to emphasise that no 'Golden standard' exists for the presence of pain (Rutherford, 2002), which means that observation of certain measures cannot be used to prove neither the presence nor the lack of pain in nonverbal individuals. What can be assessed or quantified are indicators – measurements which give indication of the nature and severity of the pain experienced – especially when sets of measures are used (as discussed by EFSA (2012) for indicators of animal welfare). However, due to the unambiguously negative relation between pain and animal welfare, we strongly believe that animals should be given the benefit of the doubt in cases where pain is suggested to be involved.

Below, we list possible indicators of pain in pigs, and describe potentially painful conditions, which have formed the basis for the current knowledge about porcine pain. Overall, knowledge about porcine indicators of pain (as is the case for

Table 11.3 List of most common indicators used in the evaluation of painful conditions in pigs

Indicators	Description
Non-evoked behavioural responses	Assessment of spontaneously occurring behaviours, time budgets and the occurrence of certain relevant behavioural elements, such as abnormal behaviour
Motivational tasks	Assessment of avoidance learning and preferences. Demonstrate whether animals are able to learn, make decisions and behave in a way as to avoid/relieve pain
Evoked behavioural responses	Assessment of experimentally-induced responses through manipulation of the body in order to elicit withdrawal reflexes (e.g. heat/pressure inducing tail flick/leg lift)
Vocalisation	Assessment of changes in characteristics of otherwise normal vocalisations in response to pain (e.g. screams, squeals)
Facial expressions	Assessment of changes in facial expressions following a painful procedure or condition, and based on specific morphological features of the face of the animal (e.g. Piglet Grimace Scale)
Clinical	Assessment of measures macroscopically or through the use of simple devices (e.g. stethoscope). Measures of productivity. Presence of lesions of different tissue types and changes in locomotion (e.g. lameness)
Physiology and histopathological measures	Assessment of metabolic, immunologic and inflammatory biomarkers (e.g. cortisol, substance P) Assessment of tissue injury at microscopic level (e.g. lesions in the dental cavity)
Pain scales	Assessment of several measures taken over a short period of time – behavioural, clinical and physiological – and used to calculate one numerical pain score per animal.

the other farm animals as well (Prunier et al., 2013)) comes from studies of: (1) model studies, where tissue damage is induced experimentally; (2) pain evoked by tissue damaging procedures common to modern pig production; or (3) naturally occurring diseases or injuries. For the chosen types of pain indicators, we have tried to organise examples according to the three main types of studies, despite the fact that the majority of the available knowledge comes from studies of procedures such as castration or tail docking, with much smaller contributions from the two other categories.

As mentioned, a large number of animal models relevant for pain are available, of which only very few involve pigs and models porcine conditions (Fosse et al., 2011a; Barington and Jensen, 2016). The use of animal pain models have been under debate (Mogil, 2009), including a call for more ecologically and clinically relevant models. Only rather recently, the pig has been included in model studies relevant for human pain (Castel et al., 2014, 2016; Di Giminiani et al., 2014; Obreja and Schmelz, 2013), and has been suggested as an advantageous animal species for such studies (Gigliuto et al., 2014).

Importantly, the results regarding pain indicators presented in this chapter come from studies highly varying in degree of controllability (from on-farm to strictly experimental) and based on rather different experimental designs and setups. Future studies of pain in pigs should bear in mind the importance of potential effects of handling, pig age (e.g. affecting the ability of the pigs to vocalise (White et al., 1995)) and blinding of observers (Tuyttens et al., 2014) in order to reduce the risk of biased results. Recently, two systematic reviews focused on the methodology used to study pain mitigation in neonatal piglets (Dzikamunhenga et al., 2014; O'Connor et al., 2014) in a critical manner. The present chapter is not using the same systematic approach, but presents examples of different types of pain indicators. One of the conclusions by Dzikamunhenga et al. (2014) was that the terms 'pain-specific behaviour' or 'pain-related behaviour' have been used inconsistently across the pig literature. In this chapter, we have avoided the use of these terms, and the use of the grouping of behavioural elements, which may not be expressing comparable underlying motivations (as argued by Herskin et al., 2016).

11.6.1 Nonevoked behavioural responses (spontaneously occurring behaviour)

Among the many types of potential pain indicators mentioned here, behaviour is often recommended (Flecknell and Waterman-Pearson, 2000) and will be dealt with first. In studies of pig welfare, the use of time budgets, and the occurrence of certain relevant behavioural elements, such as abnormal behaviour, has been used for decades.

11.6.1.1 Research models

In contrast to the animal welfare studies, spontaneously ocurring behaviour has received almost no attention in animal model studies relevant for pain. Andersen et al. (1998) studied Vietnamese potbellied pigs after surgical angioplastic procedures, and found that post-surgical onset of feeding was sensitive to pain relieving drugs. Similarly, Malavesi et al. (2006) found that after abdominal surgery, pigs were less active and started to show interest in eating later than the control animals. One possible nonevoked porcine behavioural pain indicator useful for model studies may, hence, be latency to onset of feeding after exposure to a tissue damaging procedure.

Recently, Pairis-Garcia et al. (2015b) used an experimental transient lameness model in sows, and showed that use of an NSAID (analgesic nonsteroidal antiinflammatory drug) counteracted the increased frequency of lying and decreased frequency of standing. Based on these results, other possible pain indicators may be changes in the time spent lying or standing as well as the frequency of postural changes.

11.6.1.2 Procedures common to pig production

The number of studies from modern pig production focusing on tissue damaging procedures outweighs the number of studies focusing on exsperimental tissue damage. Among the suggested pain indicators are the position of the pigs in the pen (e.g. proportion of time spent in the heated creep after tail docking (Herskin et al., 2016)), the degree of contact to pen-mates (Leslie et al., 2010), the posture of the pigs (e.g., increased lying time (Hay et al., 2003)) and the occurrence of certain behavioural elements, which, due to the anatomical location of the tissue damage on the rear part of the body, have been focused at tail/rump (such as scooting (Sutherland et al., 2008), sitting (Taylor et al., 2001), tail jamming or tail wagging (Noonan et al., 1994)), but other behaviours such as reduced suckling have also been suggested (Hay et al., 2003). Typically, for a considerable proportion of the studied behavioural variables, no effects of the tissue damage have also been reported, and — as emphasised by Dzikamunhenga et al. (2014) — the overall picture across the studies is not very clear. Possible explanations for this lack of consistency may be individual differences, different ages of pigs used, different methods of behavioural sampling, different tissue damaging procedures or differences in the timing of the behavioural recordings.

11.6.1.3 Naturally occurring tissue damage

In light of the relatively high relevance of pathological conditions reported from pigs in production systems, only remarkably few of these have been examined in terms of possible pain consequences, and even fewer of these naturally occurring conditions have been used as animal models, as has been suggested by for instance Vainio (2012) in order to increase the biological relevance of animal pain models.

Umbilical hernia and comparable conditions presented as outpouchings on the ventral aspect of the abdominal wall are relatively common in modern pig production (Petersen et al., 2008) and may develop from a number of underlying pathological conditions, such as true hernias (Andersen et al., 2014). At present it is not known whether these conditions are painful for pigs. However, Schild et al. (2015) found that the behaviour of pigs with umbilical outpouchings, and especially true hernias, differed from healthy controls. The behavioural changes overlapped with pain indicators already described in studies of castration or tail docking such as increased sitting, but also indications of changes in the opposite direction, such as reduced lying, were found.

Larsen et al. (2015) focused on a relatively common clinical finding in sow production, decubital shoulder ulcers, and found that, even though the ulcers were of moderate size (median diameter 3 cm), sows showed behavioural changes such as reduced lying time, increased frequency of postural changes and increased standing, but also increased frequency of rubbing against the fixtures of the farrowing crate and reduced nursing frequency as compared to clinically healthy control animals.

In sows, leg problems are among the major reasons for culling (Kirk et al., 2005). Fitzgerald et al. (2012) observed effects of hoof abnormalities and their severity on sow behaviour and showed that the more the hoofs were overgrown, the less the sows were standing and eating. Recently, Ison et al. (2016) examined behaviour of sows during parturition in a search for potential behavioural indicators of birth pain, and concluded that several of the typical behaviours observed during farrowing may be related to birth pain.

Taken together, the studies of nonevoked behaviour of pigs suggest that, when pigs are exposed to tissue damage, they respond by quantifiable behavioural changes, which can be observed both under conditions typical for pig production and when the animals are kept as experimental models. The majority of these variables have not been properly validated as pain indicators, but the available data suggest that inclusion of nonevoked behavioural variables in studies of pig pain has a large potential, and may form a qualified basis for future ethograms.

11.6.2 Motivational tasks

Behavioural studies involving avoidance learning and preferences include some of the most complex behavioural responses to pain, and demonstrate whether animals are able to learn, make decisions and then behave in a way as to relieve a pain state. One example is the ability to avoid locations where nociceptive stimuli are applied as well as the willingness to work to avoid such stimuli. Rats for instance, will cover electrodes in order to avoid electric shocks (Pinel et al., 1989). Another example is pain relief learning, where stimuli which have been temporally associated with termination of a noxious stimulus, gain positive valence and are preferred over neutral stimuli (Gerber et al., 2014). Only rather recently, these tasks and other manipulations of motivation, have been introduced into animal pain research, such as the use of decreased occurrence of a highly motivated behaviour (burrowing) as an indicator of pain in rats (Andrews et al., 2012). However, from the study of pig welfare, numerous investigations have taken advantage of motivational tasks. So far, only few have used the techniques on pigs in order to study pain, but increased use of these techniques in the future seems like one advantageous way to learn more about porcine pain expressions and causes of pain in pigs.

11.6.2.1 Research models

In their kaolin inflammation model of lameness, Fosse et al. (2011b) quantified lameness as well as walking speed in a test situation, where piglets had to cross a wooden ramp to get to their mother/siblings, while nursing grunts from the sow was being played back.

11.6.2.2 Procedures common to pig production

Despite the large scientific focus on potential pain consequences of tissue damaging husbandry procedures, only very few and recent studies have used motivational tasks to learn about the pain from castration or tail docking. Bilsborrow et al. (2016) exposed piglets to a navigation test after castration and found slower navigation in the castrated pigs, which was counteracted by the use of an NSAID. Interestingly, no significant associations were found between piglet behaviour in the home pen and test responses during the minutes after castration.

11.6.2.3 Naturally occurring tissue damage

The only example we could find of the use of motivational tasks to study consequences of naturally occurring tissue damage in pigs was the use of a feed reward collection test in lame sows. Here, Bos et al. (2015) found that both moderately and severely lame sows were limited in their combined ability and willingness to walk, but did not reveal an effect of mild lameness on mobility. These findings suggest that moderately and more severely lame sows, but not mildly lame sows, might suffer from reduced access to valuable resources in group housing systems.

11.6.3 Evoked behavioural responses (experimentally-induced responses)

In addition to observation of changes in nonevoked behaviours or motivational tasks, quantification of responses following experimental manipulation, particularly behavioural responses of pigs to standardised application of external noxious stimuli, has become a widely used method to evaluate changes in the somatosensory system evoked by tissue damaging conditions. In pigs, the study of nociceptive responses was initiated in the 1980s by Dantzer et al. (1986) using electric stimulation, and followed by studies applying contact thermal stimuli (Rushen and Ladewig, 1991). Later, laser-based radiant heat was used as stimulus in periparturient sows (Jarvis et al., 1997a, b), on legs and shoulders of standing gilts (Herskin et al., 2009) and on flanks and hind legs of growing pigs (Di Giminiani et al., 2013). Typical responses to thermal nociceptive stimuli have been leg lifting, kicking, tail flicking or muscle twitching. Concurrent with the availability of commercial assays for the study of nociceptive responses in other mammals, pig studies have used von Frey hairs (Castel et al., 2014) and different types of pressure algometers (Nalon et al., 2015) to quantify mechanical nociceptive thresholds. There are, however, also examples of studies developing new setups for pigs inspired by rodent assays such as the plantar stimulator developed by Sandercock et al. (2009).

11.6.3.1 Research models

Determining the efficacy of analgesia, for either human or pig applications, have been target of investigation of induced inflammatory pain in pigs of varying ages. For example, piglets were injected with kaolin in the hind legs (Fosse et al., 2011) or sows exposed to a transient chemical synovitis model of lameness (Pairis-Garcia et al., 2015b). In these studies, the avoidance responses to a mechanical challenge indicated that, similarly to other mammalian species, sensitisation induced by the inflammation occurred in pigs. Castel et al. (2014) determined sensitisation following an incision of the skin and muscle in the rump of young pigs as a model of surgical pain, and later, Castel et al. (2016) studied sensitisation in a pig model for chronic neuropathic pain caused by surgically-induced peripheral neuritis.

Withdrawal responses to thermal and mechanical noxious stimuli to the flank and legs of pigs provided important information on the efficacy of a receptor—agonist designed for the treatment of human pain (Brown et al., 2015). In addition, experimental models of inflammatory hyperalgesia have been applied to pig skin to determine the occurrence of local sensitisation. Irradiation of the skin with UVB-light resulted in a decrease in response latencies, suggesting that the porcine inflammatory response is homologous with the process observed in humans (Di Giminiani et al., 2014). Injection of a neurogenic inflammatory agent has been used to quantify thresholds of sensitivity in pigs, measuring foot withdrawal responses to noxious mechanical force (Sandercock et al., 2009), and again quantification of changes in thresholds of nociception, as a consequence of local sensitisation, was possible through assessment of experimentally induced responses.

Tail biting is an abnormal behaviour in pigs leading to injury of the tail of pen mates (Valros, Chapter 5: Tail biting). Only very recently, a surgical model of tail amputation has been used to study changes in thresholds of nociception towards a mechanical challenge (Di Giminiani et al., 2016b) (Fig. 11.2).

11.6.3.2 Procedures common to pig production

Despite the large scientific focus on potential pain consequences of these procedures, only very few and recent studies have examined possible changes in the processing of nociceptive stimuli in the somatosensory system after castration or other tissue damaging procedures common to pig production. Lomax (2015) used a mechanical challenge, delivered by von Frey filaments, to determine the efficacy of a local anaesthetic applied directly to the injured tissue and quantified via evoked behavioural responses.

11.6.3.3 Naturally occurring tissue damage

As compared to the tissue damaging procedures known from pig production, a higher number of studies have quantified evoked behavioural responses in consequence of tissue damage of a spontaneous nature, such as inflicted by the housing system or by other pigs. One large welfare problem among growing pigs and sows is lameness (Jensen et al., 2012), which has received substantial scientific interest during recent years. In addition to the studies of experimentally induced lameness mentioned above, researchers have applied pressure algometry to limbs of sows with naturally occurring lameness (Nalon et al., 2013). In addition, Dahl-Pedersen et al. (2013) scored evoked behavioural responses of sows towards palpation of the

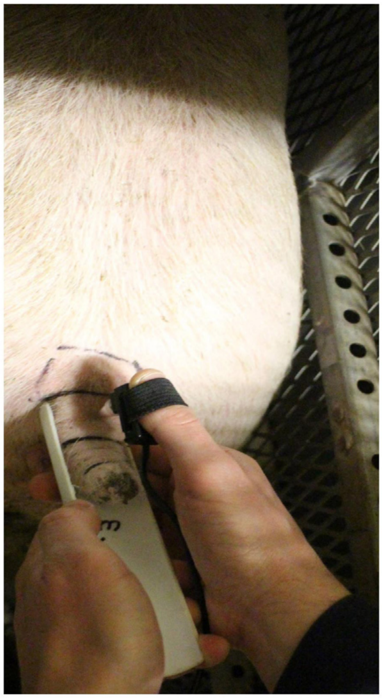

Figure 11.2 Application of a pressure application measurement device to detect changes in thresholds of nociception following a surgical model of tail amputation (Di Giminiani et al., 2016b).

shoulder area, a less standardised nociceptive stimulation, in order to study changes in sensitivity induced by decubital shoulder ulcers.

11.6.4 Vocalisation

The most preeminent element of communication in pigs is vocal, with a large array of recognised sounds produced in several contexts. It is, thus, not surprising that a growing body of evidence has been produced to suggest that changes in otherwise normal vocalisations are observed in response to tissue damage and pain arising from husbandry procedures (such as castration) or spontaneous events (such as a piglet being squeezed under the body of the sow (Illmann et al., 2008). However, interpretation of vocalisation as a pain response requires consideration of its adaptive value, as some painful events induce vocalisation while others may suppress it. Despite the clear evidence for vocalisation as indicative of pain in pigs (at least during the acute phase after tissue damage), to the best of our knowledge, neither model studies nor studies of naturally occurring tissue damage have focused on porcine vocalisations as indicator of pain. This is especially remarkable for the model studies, where focus often is on the acute phase, and less so for the naturally occurring tissue damage, which is often studied on a more long-term basis.

11.6.4.1 Procedures common to pig production

Responses of piglets to castration have been the main focus in the investigation of pain-related vocalisations. In a pioneering study, Weary et al. (1998) reported an increase in the number of high frequency screams emitted by piglets undergoing castration. Although neonatal pigs normally appear to emit high frequency calls in response to handling and restraint, the occurrence was higher in the event of castration, and vocal responses have proved to be able to separate the different parts of the procedure, showing that especially the cutting and pulling of the spermatic cord induces the high frequency vocalisations (Taylor and Weary, 2000). Marx et al. (2003) observed a comprehensive alteration in sound parameters during castration, with more extended and more powerful calls produced by castrated piglets than by control animals. The researchers utilised detailed spectrogram analyses and identified three different types of calls: grunts, squeals and screams. Piglets castrated without anaesthesia emitted more screams than the other call types, which were interpreted as an indicator of perceived pain. The intensity of the calls emitted by castrated piglets was found to be reduced by the application of a local anaesthetic (Hansson et al., 2011) and this reversibility of the response provides strong support in favour of the use of vocalisation as an indicator of pain in pigs.

11.6.5 Facial expressions of pain (piglet grimace scale)

In the past decade, a new methodology for the evaluation of pain has been developed in rodents and is now finding its application in larger animal species as well. A Grimace Scale is a scoring system allowing the evaluation of changes in facial expressions following a painful procedure or condition, and is based on specific morphological features of the face of the animal. The first scale was developed in mice (Langford et al., 2010) and was successful in detecting changes evoked by for instance acute postsurgical pain. At present, a scale is under development for use in pigs to evaluate potential effects of tail docking and castration on the facial expressions of neonatal animals (Di Giminiani et al., 2016a).

11.6.6 Clinical assessment

The term ‘clinical measure’ has no rigid definition. In this chapter, we mention measures that can be obtained macroscopically or by use of simple devices such as a stethoscope, as well as measures of productivity. The validity of the latter as pain indicators in high-producing animal breeds has been discussed due to the reported low specificity and sensitivity of these measures. Other clinical indicators, the specificity of which in terms of pain have not been examined yet, is the presence of lesions of different tissue types and changes in locomotion such as lameness. However, even though both clinical examinations of lesions and gait provide information about possible pain, not all lesions are associated with pain, and the same holds for changes in locomotion.

11.6.6.1 Research models

The review by Bradbury et al. (2015) revealed that only remarkably few model studies involving porcine surgery reported whether and how the pain level of the animals was assessed. There are, however, examples of model studies reporting possible relations between clinical findings and pain in pigs. Harvey-Clark et al. (2000) found reduced food intake in pigs after surgery and, by examining gait in sows subjected to a transient lameness model, Pairis-Garcia et al. (2015a) found positive effects of provision of a NSAID, leading the authors to suggest that analgesic drugs may be a key tool to manage pain states associated with lameness in sows.

11.6.6.2 Naturally occurring

Conditions of a degenerative nature are commonly observed in pigs through clinical signs of lameness. The most recurrent degenerative joint disease in pigs is osteochondrosis, involving lesions in the articular surface and cartilage. It is now possible to identify lesions of this nature through radiography, computed tomography and histopathology. These clinical methods of assessment have already found application in pigs and provide fundamental information to the identification of the condition associated with clinical lameness (Bertholle et al., 2016). However, so far the link between these measures and pain is not known.

Grading systems to evaluate gait and lameness in pigs are available (D'Eath, 2012). Recently, Meijer et al. (2015) showed effects of an opioid analgesic on gait of lame pigs in a test situation, and Stavrakakis et al. (2015) used walking kinematics to characterise lame sows before and after the diagnosis of lameness. The methods used in these studies provide promising tools for future research into early pain recognition and lameness treatment in pigs.

11.6.7 Physiological responses and histopathological measures

Besides the physiological changes mediated by the sympathetic adrenomedullary system and the HPA-axis, different metabolic, immunologic and inflammatory measures may be used as indirect animal pain indicators (as reviewed by Prunier et al. (2013). However, for the majority of these (as reviewed by Viñuela-Fernandez et al. (2007) and Mellor et al. (2000)), some limitations exist, such as their lack of specificity to pain and the possibility to reach ceiling effects. In addition, the mere sampling of for instance blood is often stressful for pigs (Herskin and Jensen, 2002) unless care is taken to pick the least aversive method (Prunier et al., 2005) or to habituate the pigs to the procedure. Hence, in studies focusing on physiological consequences of tissue damage, the inclusion of proper control groups is crucial.

11.6.7.1 Research models

Experimental surgical models have been used to investigate pre- and post-procedural changes in cortisol levels. Malavesi et al. (2006) found that administration of a topical opioid analgesic to pigs after abdominal surgery led to reduced plasma concentration of cortisol. Lykkegaard et al. (2005) undertook experimental laparotomy in domestic pigs (all anesthetised) and gave a local anaesthetic on top to one group. The local anaesthetic led to a reversal of the effect of surgery on ACTH and cortisol.

11.6.7.2 Procedures common to pig production

Several of the studies on pain consequences of porcine castration have included quantification of HPA-axis activity. Piglets undergoing castration exhibit higher levels of cortisol immediately following the procedure (Lonardi et al., 2015). Although with some discrepancies in the reports, the general consensus is that tail docking can also induce an increase in cortisol (Sutherland et al., 2011). In addition, other husbandry procedures have been associated with an increase in cortisol levels such as ear notching as opposed to ear tagging (Marchant-Forde et al., 2009), injections rather than oral administration of iron (Marchant-Forde et al., 2009), as well as teeth clipping and teeth grinding (Prunier et al., 2005). The use of analgesics for these procedures have provided support to the value of the physiological indicators, as the administration of analgesia or local anaesthesia resulted in the reduced or attenuated levels of cortisol in piglets undergoing castration (Keita et al., 2010) or tail docking and iron injections (Bates et al., 2014).

Only few studies have included quantification of inflammatory markers. After tail docking, Sutherland et al. (2012) observed that C-reactive protein (CRP) tended to be increased and did not see changes in Substance P or in white blood cell counts.

The most common physiological measure used as indicator of the sympathetic pain response in the pig literature is skin temperature. The results, however, bear some discrepancies. For example, ear temperature has been reported to be higher in piglets castrated without compared to those receiving analgesia (Hansson et al., 2011). By contrast, castrated, tail docked and iron-injected piglets with transmammarily administered NSAID had higher cranial temperature than those given placebo (Bates et al., 2014). More recently, eye and rectal temperature were recorded higher in castrated piglets for several hours following the procedure (Lonardi et al., 2015). In addition, cardiovascular responses to noxious stimulation have been measured in pigs to assess the efficacy of anaesthesia (Haga et al., 2001), showing increased mean arterial blood pressure (MAP). A similar increase was observed in piglets undergoing castration without local anaesthesia (Haga and Ranheim, 2005), in contrast to piglets receiving an intratesticular or intrafunicular local anaesthetic.

Histopathology has been used to evaluate tissue injury at microscopic level after procedures common to pig production. For example, lesions induced by teeth clipping and grinding have been observed in the pulp cavity opening, in addition to fractures, haemorrhage, infiltration and abscesses (Hay et al., 2004). The majority of these were of greater severity in piglets exposed to teeth clipping than grinding, and as the lesions were observed for relatively long periods of time, they were suggested as a major cause of pain.

A similar analysis of tissue injury was carried out on samples obtained from the stump of tail-docked piglets (Sandercock et al., 2016). The study suggested that inflammatory epidermal and dermal changes were evident, and provided information on the healing process of tissue injured by this specific husbandry procedure.

11.6.7.3 Naturally occurring tissue damage

Examples of studies focusing on physiological indicators of pain of a spontaneous nature are few. Pain associated with farrowing has been investigated through quantification of levels of cortisol/ACTH (Lawrence et al., 1994). The relationship between parturition pain and neuroendocrine hormones is also supported by observations that cortisol concentration gradually increased with births of consecutive piglets (Jarvis et al., 1998) and that its levels were higher following birth of larger piglets (Jarvis et al., 1998).

Histopathology has also been used to determine the extent of tissue trauma following spontaneous conditions. In a study investigating the traumatic nature of bruises observed in pigs at the time of slaughter, the skin affected by trauma was reported to present haemorrhage and cellular infiltrations (Barington and Jensen, 2013). However, no validation in terms of pain was done.

11.6.8 Pain scales

In other mammals kept by man – especially laboratory rodents (Morton and Griffiths, 1985) and typical veterinary patients such as dogs and cats (Firth and Haldane, 1999; Brondani et al., 2011) – pain scales have been established and validated. Typically a pain scale consists of several measures taken over a short period of time – behavioural, clinical and physiological – and used to calculate one numerical pain score per animal. Even though the development of similar tools has been requested for some years (Søndergaard et al., 2011), to date validated porcine pain scales are not available.

Reyes et al. (2002) examined postoperative pain relief in minipigs following implantation of a central arterial catheter via an inguinal incision, and used a multifactorial numerical rating scale inspired by rodent scales, and showed that the use of NSAIDs was able to normalise the pain scores. Later, the same scale was used by Murison et al. (2009) in pigs undergoing laryngeal transplantation.

In a review on the need for a cross-species approach to the study of pain in animals, Paul-Murphy et al. (2004) discussed the creation of pain scales, and how such should take into consideration specific animal characteristics such as species, breed, environment, rearing conditions, developmental stage, age, sex, differences related to the specific cause of pain, the body region affected, and the specific character of the pain. The knowledge about pig pain provided in this chapter highlights the importance of these reservations, rendering the future development of porcine pain scales a highly important, but also comprehensive task.

11.7 Conclusions/Future trends

Despite the fact that animal welfare concerns in the last decades have prompted pain research in pigs, it is unfortunately still limited due to issues such as the lack of suitable pain models, problems associated with the use of farm animals in research environments, and economic issues including an apparent lack of demand for new analgesics for agricultural species. The knowledge provided in this chapter – and especially the many recent studies – suggest that the situation is currently under change, which has to some extent been driven by studies of pig as models for humans. However, a significant, targeted pain research effort within somatic, visceral as well as neuropathic pain, is needed in order for the pig – despite its sensitivity to pain – to be given the attention which is warranted in order to ensure the appropriate animal welfare. As of today, evaluation of pain from naturally occurring conditions is still not part of typical on-farm welfare assessments, and neither in production systems nor in the laboratory, do pigs receive pain relief corresponding to other animal species. Even though there has been a recent interest in conditions potentially causing chronification of pain in farm animals, we are still far from the target and increasing animal welfare standards call for further research into plasticity changes within the central nervous system resulting in long lasting hyperalgesia due to untreated or prolonged pain, as well as the development of methodology to quantify chronic pain in pigs. Another aspect of animal sentience to target in the future is the effect of porcine pain on the welfare of other pigs – empathy – as evidence from e.g. mice suggest that the nociceptive sensitivity of these animals can be augmented by observing a cagemate in pain (Langford et al., 2006). Evidence for emotional contagion of distress in young pigs has been recently suggested (Goumon and Spinka, 2016) and future focus should be directed at the possibility of social support acting to alleviate pain.

References

Ackerknecht, E.H., 1974. The history of the discovery of the vegetative (autonomic) nervous system. Med. Hist. 18, 1–8.

Andersen, E.M.O., Spangsberg, R., Pedersen, K.S., Barington, K., Jensen, H.E., 2014. Umbilical hernia and differential diagnoses in slaughter pigs. In: Proceedings of the 23rd International Pig Veterinary Society (IPVS) Congress 8–11th of June, Cancun, Quintana Roo, Mexico, p. 126.

Andersen, H.E.A., Fosse, R.T., Juiper, K.K.J., Nordrehaug, J.E., Pettersen, R.J., 1998. Ketorolac (Toradol ®) as an analgesic in swine following transluminal coronary angioplasty. Lab. Animals 32, 307–315.

Andrews, N., Legg, E., Lisak, D., Issop, Y., Richardson, D., Harper, S., Pheby, T., Huang, W., Burgess, G., Machin, I., Rice, A.S.C., 2012. Spontaneous burrowing behaviour in the rat is reduced by peripheral nerve injury or inflammation associated pain. Eur. J. Pain 16, 485–495.

Apkarian, A.V., Baliki, M.N., Farmer, M.A., 2013. Predicting transition to chronic pain. Curr. Opin. Neurol. 26, 360–367.

Bantel, C., Trapp, S., 2011. The role of the autonomic nervous system in acute surgical pain processing – what do we know? Anaesthesia 66, 541–544.

Barington, K., Jensen, H.E., 2013. Forensic cases of bruises in pigs. Vet. Rec. 173, 526.

Barington, K., Jensen, H.E., 2016. The impact of force on the timing of bruises evaluated in a porcine model. J. Forensic. Leg. Med. 40, 61–66.

Bates, J.L., Karriker, L.A., Stock, M.L., Pertzborn, K.M., Baldwin, L.G., Wulf, L.W., Lee, C. J., Wang, C., Coetzee, J.F., 2014. Impact of transmammary-delivered meloxicam on biomarkers of pain and dDistress in piglets after castration and tail docking. PLoS. ONE 9, e113678.

Bateson, P., 1991. Assessment of pain in animals. Anim. Behav. 42, 827–839.

Baxter, E.M., Edwards, S.A., 2017. Piglet mortality and morbidity: inevitable or unacceptable? In: Špinka, M. (Ed.), Advances in Pig Welfare. Woodhead Publishing, Duxford, UK.

Bentham, J., 1789. The Principles of Morals and Legislation. Prometheus Books, UK, 352 pp.

Bertholle, C.P., Meijer, E., Back, W., Stegeman, A., van Weeren, P.R., van Nes, A., 2016. A longitudinal study on the performance of in vivo methods to determine the osteochondrotic status of young pigs. BMC. Vet. Res. 12.

Bilsborrow, K., Seddon, Y.M., Brown, J., Waldner, C., Stookey, J.M., 2016. An investigation of a novel behavioural test to assess pain in piglets following castration. Can. J. Anim. Sci. 96, 376–385.

Blackburn-Munro, G., Blackburn-Munro, R.E., 2001. Chronic pain, chronic stress and depression: coincidence or consequence? J. Neuroendocrinol. 13, 1009–1023.

Bos, E.J., Nalon, E., Maes, D., Ampe, B., Buijs, S., van Riet, M.M.J., Millet, S., Janssens, G. P.J., Tuyttens, F.A.M., 2015. Effect of locomotion score on sows' performances in a feed reward collection test. Animal 9, 1698–1703.

Bradbury, A.G., Eddleston, M., Clutton, R.E., 2015. Pain management in pigs undergoing experimental surgery; a literature review (2012–2014). Br. J. Anaesth. Available from: http://dx.doi.org/10.1093/bja/aev301.

Brondani, J.T., Luna, S.P., Padovani, C.R., 2011. Refinement and initial validation of a multidimensional composite scale for use in assessing acute postoperative pain in cats. Am. J. Vet. Res. 72, 174–183.

Brown, J.D., Saeed, M., Do, L., Braz, J., Basbaum, A.I., Iadarola, M.J., Wilson, D.M., Dillon, W.P., 2015. CT-guided injection of a TRPV1 agonist around dorsal root ganglia decreases pain transmission in swine. Sci. Transl. Med. 7, 305ra145.

Bryant, R.V., van Langenberg, D.R., Holtmann, G.J., Andrews, J.M., 2011. Functional gastrointestinal disorders in inflammatory bowel disease: Impact on quality of life and psychological status. J. Gastroenterol. Hepatol. 26, 916–923.

Carroll, J.A., Berg, E.L., Strauch, T.A., Roberts, M.P., Kattesh, H.G., 2006. Hormonal profiles, behavioural responses, and short-term growth performance after castration of pigs at three, six, nine, or twelve days of age. J. Anim. Sci. 84, 1271–1278.

Castel, D., Willentz, E., Doron, O., Brenner, O., Meilin, S., 2014. Characterization of a porcine model of post-operative pain. Eur. J. Pain 18, 496–505.

Castel, D., Naveh, M., Aharon, A., Doron, O., Meilin, S., 2016. Prolonged analgesic effect of PRF-108 and PRF-110 in postoperative pain in pigs. Pain Therapy. Available from: http://dx.doi.org/10.1007/s40122-015-0043-9.

Cervero, F., 1999. Visceral pain. Lancet 353, 2145–2148.

Cervero, F., 2012. Understanding Pain. MIT Press, Massachusetts, pp. 1–84.

Dahl-Pedersen, K., Bonde, M.K., Herskin, M.S., Jensen, K.H., Kaiser, M., Jensen, H.E., 2013. Pathogenesis and pathology of shoulder ulcerations in sows with special reference to peripheral nerves and behavioural responses to palpation. Vet. J. 198, 666–671.

Dantzer, R., Bluthé, R., Tazi, A., 1986. Stress-induced analgesia in pigs. Ann. Rech. Vet. 17, 147–151.

Di Giminiani, P., Petersen, L.J., Herskin, M.S., 2013. Nociceptive responses to thermal and mechanical stimulations in awake pigs. Eur. J. Pain 17, 638–648.

Di Giminiani, P., Petersen, L.J., Herskin, M.S., 2014. Characterization of nociceptive behavioural responses in the awake pig following UV-B-induced inflammation. Eur. J. Pain 18, 20–28.

Di Giminiani, P., Stausholm, J.S., Viitasaari, E., Petersen, L.J., Herskin, M.S., 2015. The effect of social isolation, gender and familiarity with the experimental procedure on tests of porcine nociceptive thresholds. Vet. Anaesth. Analg. 42, 648–656.

Di Giminiani, P., Brierley, V.L.M.H., Scollo, A., Gottardo, F., Malcolm, E.M., Edwards, S.A., Leach, M.C., 2016a. The assessment of facial expressions in piglets undergoing tail docking and castration: towards the development of the Piglet Grimace Scale. Front. Vet. Sci. (in press).

Di Giminiani, P., Sandercock, D.A., Malcolm, E.M., Leach, M.C., Herskin, M.S., Edwards, S.A., 2016b. Temporal changes in mechanical nociceptive thresholds in juvenile pigs subjected to surgical tail amputation: a model of injury induced by tail biting. In: 24th International Pig Veterinary Society conference 2016 Dublin, Ireland.

D'Eath, R.B., 2012. Repeated locomotion scoring of a sow herd to measure lameness: consistency over time, the effect of sow characteristics and inter-observer reliability. Animal Welfare 21, 219–231.

Dzikamunhenga, R.S., Anthony, R., Coetzee, J., Gould, S., Johnson, A., Karriker, L., McKean, J., Millman, S.T., Niekamp, S.R., O'Connor, A.M., 2014. Pain management in the neonatal piglet during routine management procedures. Part 1: a systematic review of randomized and non-randomized intervention studies. Anim. Health. Res. Rev. 15, 14–38.

EFSA Panel on Animal health and Welfare, 2012. Statement on the use of animal-based measures to assess the welfare of animals. EFSA J. 10, 2767.

Egger, C.M., Love, L., Doherty, T. (Eds.), 2014. Pain Management in Veterinary Practice. John Wiley and Sons, Oxford, UK, 447 pp.

Eisenbarth, H., Rukwied, R., Petersen, M., Schmelz, M., 2004. Sensitization to bradykinin B1 and B2 receptor activation in UV-B irradiated human skin. Pain 110, 197–204.

Eisenberger, N.I., Lieberman, M.D., Williams, K.D., 2003. Does rejection hurt? An FMRI study of social exclusion. Science 302, 290–292.

Farm Animal Welfare Council. Press Statement, 1979. Available at: <http://webarchive.nationalarchives.gov.uk/20121007104210/http://www.fawc.org.uk/pdf/fivefreedoms1979.pdf>.

Firth, A.M., Haldane, S.L., 1999. Development of a scale to evaluate postoperative pain in dogs. J. Am. Vet. Med. Assoc. 214, 651–659.

Fitzgerald, R.F., Stalder, K.J., Karriker, L.A., Sadler, L.J., Hill, H.T., Kaisand, J., Johnson, A.K., 2012. The effect of hoof abnormality on sow behaviour and performance. Livestock Sci. 145, 230–238.

Flecknell, P.A., Waterman-Pearson, A., 2000. Pain Management in Animals. WB Saunders, London, p. 184.

Flor, H., Turk, D.C., 2011. Chronic Pain – An Integrated Biobehavioral Approach. IASP Press, Seattle, pp. 3–44.

Foltán, R., Klima, K., Spackova, J., Sedý, J., 2008. Mechanism of traumatic neuroma development. Med. Hypotheses. 71, 572–576.

Food and Agricultural Organization of the United Nations. 2009. The state of food and agriculture, FAO Rome, Italy, 180 pp.

Fosse, T.K., Spadavecchia, C., Horsberg, T.E., Haga, H.A., Ranheim, B., 2011a. Pharmacokinetics and pharmacodynamic effects of meloxicam in piglets subjected to a kaolin inflammation model. J. Vet. Pharmacol Therap. 34, 367–375.

Fosse, T.K., Toutain, P.L., Spadavecchia, C., Haga, H.A., Horsberg, T.E., Ranheim, B., 2011b. Ketoprofen in piglets: enantioselective pharmacokinetics, pharmacodynamics and PK/PD modelling. J. Vet. Pharmacol. Therap. 34, 338–349.

Gaynor, J.S., Muir, W.W., 2015. Handbook of Veterinary Pain Management. third ed. Elsevier Mosby, Missouri, p. 620.

Gerber, B., Yarali, A., Diegelmann, S., Wotjak, C.T., Pauli, P., Fendt, M., 2014. Pain-relief learning in flies, rats and man: basic research and applied perspectives. Learn. Memory 21, 232–252.

Gigliuto, C., De Gregorio, M., Malafoglia, V., Raffaeli, W., Compagnone, C., Visai, L., Petrini, P., Avanzini, M.A., Muscoli, C., Viganò, J., Calabrese, F., Dominioni, T., Allegri, M., Cobianchi, L., 2014. Pain assessment in animal models: do we need further studies? J. Pain Res. 7, 227–236.

Giuffra, E., Kijas, J.M.H., Amarger, V., Carlborg, Ö., Jeon, J.-T., Andersson, L., 2000. The origin of the domestic pig: independent domestication and subsequent introgression. Genetics. 154, 1785–1791.

Goumon, S., Spinka, M., 2016. Emotional contagion of distress in young pigs is potentiated by previous exposure to the same stressor. Anim. Cogn. 19, 501–511.

Gregory, N.S., Harris, A.L., Robinson, C.R., Dougherty, P.M., Fuchs, P.N., Sluka, K.A., 2013. An overview of animal models of pain: disease models and outcome measures. J. Pain. 14, 1255–1269.

Haga, H.A., Ranheim, B., 2005. Castration of piglets: the analgesic effects of intratesticular and intrafunicular lidocaine injection. Vet. Anaesth. Analg. 32, 1–9.

Haga, H.A., Tevik, A., Moerch, H., 2001. Electroencephalographic and cardiovascular indicators of nociception during isoflurane anaesthesia in pigs. Vet. Anaesth. Analg. 28, 126–131.

Hansson, M., Lundeheim, N., Nyman, G., Johansson, G., 2011. Effect of locan anaesthesia and/or analgesia on pain responses induced by piglet castration. Acta. Vet. Scand. 53, 34.

Harley, S., More, S.J., O'Connell, N.E., Hanlon, A., Teixeira, D., Boyle, L., 2012. Evaluating the prevalence of tail biting and carcass condemnations in slaughter pigs in the Republic and Northern Ireland, and the potential of abattoir meat inspection as a welfare surveillance tool. Vet. Rec.1–7.

Harvey-Clark, C.J., Gilespie, K., Riggs, K.W., 2000. Transdermal fentanyl compared with parenteral buprenorphine in post-surgical pain in swine: a case study. Lab. Anim. 34, 386–398.

Hay, M., Vulin, A., Génin, S., Sales, P., Prunier, A., 2003. Assessment of pain induced by castration in piglets: behavioural and physiological responses over the subsequent 5 days. Appl. Anim. Behav. Sci. 82, 201–218.

Hay, M., Rue, J., Sansac, C., Brunel, G., Prunier, A., 2004. Long-term detrimental effects of tooth clipping or grinding in piglets: a histological approach. Anim. Welfare 13, 27–32.

Herskin, M.S., Jensen, K.H., 2002. Effects of open field-testing and associated handling vs handling alone on the reactivity of the HPA-axis in weaned piglets. Anim. Sci. 74, 485–491.

Herskin, M.S., Ladewig, J., Arendt-Nielsen, L., 2009. Measuring cutaneous thermal nociception in group-housed pigs using laser technique – effects of laser power output. Appl. Anim. Behav. Sci. 118, 144–151.

Herskin, M.S., Thodberg, K., Jensen, H.E., 2015. Effects of tail docking and docking length on neuroanatomical changes in healed tail tips of pigs. Animal 9, 677–681.

Herskin, M.S., Di Giminiani, P., Thodberg, K., 2016. Effects of administration of a local anesthetic and/or an NSAID and of docking length on the behaviour of piglets during five hours after tail docking. Resubmitted to Res. Vet. Sci. June 2016.

Iannetti, G., Salomons, T.V., Moayedi, M., Moraux, A., Davis, K.D., 2013. Beyond metaphor: contrasting mechanisms of social and physical pain. Trends. Cogn. Sci. 17, 371–378.

Illmann, G., Neuhauserová, K., Pokorná, Z., Chaloupková, H., Šimečková, M., 2008. Maternal responsiveness of sows towards piglet's scream vocalization during the first 24 hours post partum. Appl. Anim. Behav. Sci. 112, 248–259.

Ison, S.H., Jarvis, S., Rutherford, K.M.D., 2016. The identification of potential behavioural indicators of pain in periparturient sows. Res. Vet. Sci. 109, 114–120.

Jaggi, A.S., Jain, V., Singh, N., 2011. Animal models of neuropathic pain. Fundamental Clin. Pharmacol. 25, 1–28.

Jarvis, S., McLean, K.A., Chirnside, J., Deans, L.A., Calvert, S.K., Molony, V., Lawrence, A.B., 1997a. Opioid-mediated changes in nociceptive threshold during pregnancy and parturition in the sow. Pain 72, 153–159.

Jarvis, S., Lawrence, A.B., McLean, K.A., Deans, L.A., Chirnside, J., Calvert, S.K., 1997b. The effect of environment on behavioural activity, ACTH, beta-endorphin and cortisol in pre-farrowing gilts. Anim. Sci. 65, 465–472.

Jarvis, S., Lawrence, A.B., McLean, K.A., Chirnside, J., Deans, L.A., Calvert, S.K., 1998. The effect of environment on plasma cortisol and beta-endorphin in the parturient pig and the involvement of endogenous opioids. Anim. Reprod. Sci. 52, 139–151.

Jensen, M.P., Chodroff, M.J., Dworkin, R.H., 2007. The impact of neuropathic pain on health-related quality of life. Neurology. 68, 1178–1182.

Jensen, T.B., Kristensen, H.H., Toft, N., 2012. Quantifying the impact of lameness on welfare and profitability of finisher pigs using expert opinions. Livestock Sci. 149, 209–214.

Karanth, S.S., Springall, D.R., Kuhn, D.M., Levene, M.M., Polak, J.M., 1991. An immunocytochemical study of cutaneous innervation and the distribution of neuropeptides and protein gene-product 9.5 in man and commonly employed laboratory-animals. Am. J. Anatomy 191, 369–383.

Keita, A., Pagot, E., Prunier, A., Guidarini, C., 2010. Pre-emptive meloxicam for postoperative analgesia in piglets undergoing surgical castration. Vet. Anaesth. Analg. 37, 367–374.

Kilbride, A.L., Gillman, C.E., Green, L.E., 2009. A cross sectional study of the prevalence, risk factors and population attributable fractions for limb and body lesions in lactating sows on commercial farms in England. BMC. Vet. Res. 5, 30.

Kirk, R.K., Svensmark, B., Ellegaard, L.P., Jensen, H.E., 2005. Locomotive disorders associated with sow mortality in Danish pig herds. J. Vet. Med. 52, 423–428.

Kluivers-Poodt, M., Houx, B.B., Robben, R.M., Koop, G., Lambooij, E., Hellebrekers, L.J., 2012. Effects of local anaesthetic and NSAID in castration of piglets, on the acute pain responses, growth and mortality. Animal. 6, 1469–1475.

Korszun, A., Young, E.A., Singer, K., Carlson, N.E., Brown, M.B., Crofford, L., 2002. Basal circadian cortisol secretion in women with temporomandibular disorders. J. Dent. Res. 81, 279–283.

Langford, D.J., Crager, S.E., Shehzad, Z., Smith, S.B., Sotocinal, S.G., Levenstadt, J.S., Chanda, M.L., Levitin, D.J., Mogil, J.S., 2006. Social modulation of pain as evidence for empathy in mice. Science 312, 1967–1970.

Langford, D.J., Bailey, A.L., Chanda, M.L., Clarke, S.E., Drummond, T.E., Echols, S., Glick, S., Ingrao, J., Klassen-Ross, T., Lacroix-Fralish, M.L., Matsumiya, L., Sorge, R.E., Sotocinal, S.G., Tabaka, J.M., Wong, D., van den Maagdenberg, A.M.J.M., Ferrari, M. D., Craig, K.D., Mogil, J.S., 2010. Coding of facial expressions of pain in the laboratory mouse. Nat. Methods 7, 447-U52.

Larsen, T., Kaiser, M., Herskin, M.S., 2015. Does the presence of shoulder ulcers affect the behaviour of sows? Res. Vet. Sci. 98, 19–24.

Lawrence, A.B., Petherick, J.C., McLean, K.A., Deans, L.A., Chirnside, J., Vaughan, A., Clutton, E., Terlouw, E.M.C., 1994. The effect of environment on behavior, plasma-cortisol and prolactin in parturient sows. Appl. Anim. Behav. Sci. 39, 313–330.

Leidig, M.S., Hertrampf, B., Failing, K., Schumann, A., Reiner, G., 2009. Pain and discomfort in male piglets during surgical castration with and without local anaesthesia as determined by vocalization and defence behaviour. Appl. Anim. Behav. Sci. 116, 174–178.

Leslie, E., Hernandez-Jover, M., Newman, R., Holyoake, P., 2010. Assessment of acute pain experienced by piglets from ear tagging, ear notching and intraperitoneal injectable transponders. Appl. Anim. Behav. Sci. 127, 86–95.

Lomax, S., 2015. Assessment and amelioration of pain for improved welfare during routine husbandry procedures in piglets. Australian Pork.

Lonardi, C., Scollo, A., Normando, S., Brscic, M., Gottardo, F., 2015. Can novel methods be useful for pain assessment of castrated piglets? Animal 9, 871–877.

Lykkegaard, K., Lauritzen, B., Tessem, L., Weikop, P., Svendsen, O., 2005. Local anaesthetics attenuates spinal nociception and HPA-axis activation during experimental laparotomy in pigs. Res. Vet. Sci. 79, 245–251.

Lynn, B., Schutterle, S., Pierau, F.K., 1996. The vasodilator component of neurogenic inflammation is caused by a special subclass of heat-sensitive nociceptors in the skin of the pig. J. Physiol. Lond. 494, 587–593.

Mainau, E., Manteca, X., 2011. Pain and discomfort caused by parturition in cows and sows. Appl. Anim. Behav. Sci. 135, 241–251.

Malavesi, L.M., Nyman, G., Augustsson, H., Jacobson, M., Jensen-Waern, M., 2006. Effects of epidural morphine and transdermal fentanyl analgesia on physiology and behaviour after abdominal surgery in pigs. Lab. Anim. 40, 16–27.

Marchant-Forde, J.N., Lay Jr, D.C., McMunn, K.A., Cheng, H.W., Pajor, E.A., Marchant-Forde, R.M., 2009. Postnatal pig husbandry practices and well-being: the effects of alternative techniques delivered separately. J. Anim. Sci. 87, 1479–1492.

Marchant-Forde, J.N., Lay, D.C., McMunn, K.A., Cheng, H.W., Pajor, E.A., Marchant-Forde, R.M., 2014. Postnatal piglet husbandry practices and well-being: The effects of alternative techniques delivered in combination. J. Anim. Sci. 92, 1150–1160.

Marchant-Forde, J.N., Herskin, M.S., 2017. Pigs as laboratory animals. In: Špinka, M. (Ed.), Advances in Pig Welfare. Woodhead Publishing, Duxford, UK.

Marx, G., Horn, T., Thielebein, J., Knubel, B., von Borell, E., 2003. Analysis of pain-related vocalization in young pigs. J. Sound Vib. 266, 687–698.

McCoy, A.M., Toth, F., Dolvik, N.I., Ekman, S., Ellermann, J., Olstad, K., Ytrehus, B., Carlson, C.S., 2013. Articular osteochondrosis: a comparison of naturally-occurring human and animal disease. Osteoarthritis Cartilage 21, 1638–1647.

Meijer, E., van Nes, A., Back, W., van der Staay, F.J., 2015. Clinical effects of buprenorphine on open field behaviour and gait symmetry in healthy and lame weaned piglets. Vet. J. 206, 298–303.

Mellor, D.J., Cook, C.J., Stafford, K.J., 2000. Quantifying some responses to pain as a stressor. In: Moberg, G.P., Mench, J.A. (Eds.), The Biology of Animal Stress. CAB International, Wallingford, Oxon, UK, pp. 171–198.

Meskey, H., Bogduk, N. (Eds.), 1994. Classification of Chronic Pain: Descriptions of Chronic Pain Syndromes and Definitions of Pain Terms. second ed. IASP Press, Seattle.

Mogil, J.S., 2009. Animal models of pain: progress and challenges. Nat. Rev. 10, 283–294.

Mohling, C.M., Johnson, A., Coetzee, J.F., Karriker, L.A., Stalder, K.J., Abell, C., Tyler, H.D., Millman, S.T., 2014. Evaluation of mechanical and thermal nociception as objective tools to measure painful and non-painful lameness phases in multiparous sows. J. Anim. Sci. 92, 3073.

Molony, V., Kent, J.E., 1997. Assessment of acute pain in farm animals using behavioural and physiological measurements. J. Anim. Sci. 75, 266–272.

Molony, V., Kent, J.E., Robertson, I.S., 1995. Assessment of acute and chronic pain after different methods of castration of calves. Appl. Anim. Behav. Sci. 46, 33–48.

Morton, D.B., Griffiths, P.H.M., 1985. Guidelines on the recognition of pain, distress and discomfort in experimental animals and a hypothesis of assessment. Vet. Rec. 116, 431–436.

Murison, P.J., Jones, A., Mitchard, L., Burt, R., Birchall, M.A., 2009. Development of perioperative care for pigs undergoing laryngeal transplantation: a case series. Lab. Anim. 43, 338–343.

Nalon, E., Maes, D., Piepers, S., van Riet, M.M.J., Janssens, G.P.J., Millet, S., Tuyttens, F.A. M, 2013. Mechanical nociception thresholds in lame sows: Evidence of hyperalgesia as measured by two different methods. Vet. J. 198, 386–390.

Nalon, E., Maes, D., Piepers, S., Taylor, P., van Riet, M.M.J., Janssens, G.P.J., Millet, S., Tuyttens, F.A.M., 2015. Factors affecting mechanical nociceptive thresholds in healthy sows. Vet. Anaesth. Analg. 43, 343–355.

Nielsen, E.O., Haugegaard, S., Jørgensen, L., Sørensen, G., 2013. Gastric health in slaughter pigs and sows (In Danish). Danish Pig Research Centre, Report 975, 14 pp.

Nilsson, S., Autonomic nerve function in vertebrates, In: Zoophysiology, vol. 13, Springer-Verlag, Berlin Heidelberg, p. 6–40.

Noonan, G.J., Rand, J.S., Priest, J., Ainscow, J., Blackshaw, J.K., 1994. Behavioural observations of piglets undergoing tail docking, teeth clipping and ear notching. Appl. Anim. Behav. Sci. 39, 203–213.

Obreja, O., Schmelz, M., 2010. Single-fiber recordings of unmyelinated afferents in pig. Neurosci. Lett. 470, 175–179.

Obreja, O., Schmelz, M., 2013. The porcine nerve as a model of human pathology. In: handwerker, H.O., Arendt-Nielsen, L. (Eds.), Pain Models – Translational Relevance and Applications. IASP Press, Washington DC, pp. 227–235.

Obreja, O., Ringkamp, M., Namer, B., Forsch, E., Klusch, A., Rukwied, R., Petersen, M., Schmelz, M., 2010. Patterns of activity-dependent conduction velocity changes differentiate classes of unmyelinated mechano-insensitive afferents including cold nociceptors, in pig and in human. Pain 148, 59–69.

O'Connor, A., Anthony, R., Bergamasco, L., Coetzee, J., Gould, S., Johnson, A.K., Karriker, L.A., Marchant-Forde, J.N., Martineau, G.S., McKean, J., Millman, S.T., Niekamp, S., Pajor, E.A., Rutherford, K., Sprague, M., Sutherland, M., von Borell, E., Dzikamunhenga, R.S., 2014. Pain management in the neonatal piglet during routine

management procedures. Part 2: Grading the quality of evidence and the strength of recommendations. Anim. Health. Res. Rev. 15, 39–62.
Ohta, T., Komatsu, R., Imagawa, T., Otsuguro, K., Ito, S., 2005. Molecular cloning, functional characterization of the porcine transient receptor potential V1 (pTRPV1) and pharmacological comparison with endogenous pTRPV1. Biochem. Pharmacol. 71, 173–187.
Ossipov, M.H., Morimura, K., Porreca, F., 2014. Descending pain modulation and chronification of pain. Curr. Opin. Supportive Palliative Care 8, 143–151.
Pairis-Garcia, M.D., Johnson, A.K., Stalder, K.J., Karriker, L.A., Coetzee, J.F., Millman, S.T., 2014. Measuring the efficacy of flunixin meglumine and meloxicam for lame sows using nociceptive threshold tests. Anim. Welfare 23, 219–229.
Pairis-Garcia, M.D., Johnson, A.K., Abell, C.A., Coetzee, J.F., Karriker, L.A., Millman, S.T., Stalder, K.J., 2015a. Measuring the efficacy of flunixin meglumine and meloxicam for lame sows using a GAITFour pressure mat and an embedded microcomputer-based force plate system. J. Anim. Sci. 93, 2100–2110.
Pairis-Garcia, M.D., Johnson, A.K., Stalder, K.J., Abell, C.A., Karriker, L.A., Coetzee, J.F., Millman, S.T., 2015b. Behavioural evaluation of analgesic efficacy for pain mitigation in lame sows. Anim. Welfare. 24, 93–99.
Paul-Murphy, J., Ludders, J.W., Robertson, S.A., Gaynor, J.S., Hellyer, P.W., Wong, P.L., 2004. The need for a cross-species approach to the study of pain in animals. JAVMA 224, 692–697.
Petersen, H.H., Nielsen, E.O., Hassing, A.G., Ersbøll, A.K., Nielsen, J.P., 2008. Prevalence of clinical signs of disease in Danish finisher pigs. Vet. Rec. 162, 377–382.
Pinel, J.P.J., Symons, L.A., Christensen, B.K., Tees, R.C., 1989. Development of defensive burrowing in *Rattus norvegicus*: experience and defensive responses. J. Comp. Psychol. 103, 359–365.
Prunier, A., Mounier, A.M., Hay, M., 2005. Effects of castration, tooth resection, or tail docking on plasma metabolites and stress hormones in young pigs. Anim. Sci. 83, 216–222.
Prunier, A., Mounier, L., Le Neindre, P., Leterrier, C., Mormède, P., Paulmier, V., Prunet, P., Terlouw, C., Guatteo, R., 2013. Identifying and monitoring pain in farm animals: a review. Animal 7, 998–1010.
Reyes, L., Tinworth, K.D., Li, K.M., Yau, D.F., Waters, K.A., 2002. Observer-blinded comparison of two nonopioid analgesics for postoperative pain in piglets. Pharmacol. Biochem. Behav. 73, 521–528.
Ringkamp, M., Raja, S.N., Campbell, J.N., Meyer, R.A., 2013. Peripheral mechanisms of cutaneous nociception. In: McMahon, S.B., et al., (Eds.), Wall and Melzack's Textbook of Pain. Elsevier Saunders, Philadelphia, pp. 1–30.
Rohrbach, H., Korpivaara, T., Schatzmann, U., Spadavecchia, C., 2009. Comparison of the effects of the alpha-2 agonists detomidine, romifidine and xylazine on nociceptive withdrawal reflex and temporal summation in horses. Vet. Anaesth. Analg. 36, 384–395.
Rollin, B., 1989. The Unheeded Cry: Animal Consciousness, Animal Pain, and Science. Oxford University Press, New York, pp. xii, 117–118, cited in Carbone 2004, p. 150.
Royal, J.M., Settle, T.L., Bodo, M., Lombardini, E., Kent, M.L., Upp, J., Rothwell, S.W., 2013. Assessment of postoperative analgesia after application of ultrasound-guided regional anesthesia for surgery in a swine femoral fracture model. J. Am. Assoc. Lab. Anim. Sci. 52, 265–276.
Rukwied, R., Dusch, M., Schley, M., Forsch, E., Schmelz, M., 2008. Nociceptor sensitization to mechanical and thermal stimuli in pig skin in vivo. Eur. J. Pain 12, 242–250.

Rushen, J., Ladewig, J., 1991. Stress-induced hypoalgesia and opioid inhibition of pig's responses to restraint. Physiol. Behav. 50, 1093–1096.

Rutherford, K.M.D., 2002. Assessing pain in animals. Anim. Welf 11, 31–53.

Sandercock, D.A., Gibson, I.F., Brash, H.M., Rutherford, K.M.D., Scott, E.M., Nolan, A.M., 2009. Development of a mechanical stimulator and force measurement system for the assessment of nociceptive thresholds in pigs. J. Neurosci. Methods 182, 64–70.

Sandercock, D.A., Smith, S.H., Di Giminiani, P., Edwards, S.A., 2016. Histopathological characterization of tail injury and traumatic neuroma development after tail docking in piglets. J. Comp. Pathol. 155, 40–49.

Schild, S.-L.A., Rousing, T., Jensen, H.E., Barington, K., Herskin, M.S., 2015. Do umbilical outpouchings affect the behaviour or clinical condition of pigs during 6 h housing in a pre-transport pick-up facility? Res. Vet. Sci. 101, 126–131.

Sherrington, C., 1906. The Integrative Action of the Nervous System. Yale University Press, New Haven, CT.

Sheu, S.-Y., Wang, W.-L., Fu, Y.-T., Lin, S.-C., Lei, Y.-C., Liao, J.-H., Tang, N.-Y., Kuo, T.-F., Yao, C.-H., 2014. The pig as an experimental model for mid dermal burns research. Burns. 40, 1679–1688.

Simonsen, H.B., Klinken, L., Bindseil, B., 1991. Histopathology of intact and docked pig tails. Br. Vet. J. 147, 407–412.

Smith, E.S.J., Lewin, G.R., 2009. Nociceptors: a phylogenetic view. J. Comp. Physiol. A. 195, 1089–1106.

Sneddon, L.U., Elwood, R.W., Adamo, S.A., Leach, M.C., 2014. Defining and assessing animal pain. Anim. Behav. 97, 201–212.

Søndergaard, L.V., Dagnæs-Hansen, F., Herskin, 2011. Welfare assessment in porcine biomedical research – Suggestion for an operational tool. Res. Vet. Sci. 91, e1–e9.

Stavrakakis, S., Guy, J.H., Syranidis, I., Johnson, G.R., Edwards, S.A., 2015. Pre-clinical and clinical walking kinematics in female breeding pigs with lameness: A nested case-control cohort study. Vet. J. 205, 38–43.

Sutherland, M.A., Bryer, P.J., Krebs, N., McGlone, J.J., 2008. Tail docking in pigs: acute physiological and behavioural responses. Animal. 2, 292–297.

Sutherland, M.A., Davis, B.L., McGlone, J.J., 2011. The effect of local or general anesthesia on the physiology and behavior of tail docked pigs. Animal. 5, 1237–1246.

Sutherland, M.A., Davis, B.L., Brooks, T.A., Coetzee, J.F., 2012. The physiological and behavioural response of pigs castrated with and without anesthesia or analgesia. J. Anim. Sci. 90, 2211–2221.

Swaby, H., Gregory, N.G., 2012. A note on the frequency of gastric ulcers detected during post-mortem examination at a pig abattoir. Meat Sci. 90, 269–271.

Swindle, M.M., Smith, A.C., 2015. Swine in the Laboratory: Surgery, Anesthesia, Imaging, and Experimental Techniques. third ed. CRC Group, Taylor & Francis Group, Boca Raton, FL, 593 pp.

Tapper, K.R., Johnson, A.K., Karriker, L.A., Stalder, K.J., Parsons, R.L., Wang, C., Millman, S.T., 2013. Pressure algometry and thermal sensitivity for assessing pain sensitivity and effects of flunixin meglumine and sodium salicylate in a transient lameness model in sows. Livestock Sci. 157, 245–253.

Taylor, A.A., Weary, D.M., 2000. Vocal response of piglets to castration: identifying procedural sources of pain. Appl. Anim. Behav. Sci. 70, 17–26.

Taylor, A.A., Weary, D.M., Lessard, M., Braithwaite, L., 2001. Behavioural responses of piglets to castration: the effect of piglet age. Appl. Anim. Behav. Sci. 73, 35–43.

Tsang, A., Von Korff, M., Lee, S., Alonso, J., Karam, E., Angermeyer, M.C., Borges, G.L., Bromet, E.J., Demytteneare, K., de Girolamo, G., de Graaf, R., Gureje, O., Lepine, J. P., Haro, J.M., Levinson, D., Oakley Browne, M.A., Posada-Villa, J., Seedat, S., Watanabe, M., 2008. Common chronic pain conditions in developed and developing countries: gender and age differences and comorbidity with depression-anxiety disorders. J. Pain. 9, 883–891.

Tuyttens, et al., 2014. Observer bias in animal behaviour research: can we believe what we score, if we score what we believe? Anim. Behav. 90, 273–280.

Vainio, U., 2012. Translational animal models using veterinary patients – an example of canine osteoarthritis. Scand. J. Pain 3, 84–89.

Valros, A., 2017. Tail biting. In: Špinka, M. (Ed.), Advances in Pig Welfare. Woodhead Publishing, Duxford, UK.

Van der Avoort, D.J.J.C., Horvius, S.E.R., Selles, R.W., van Neck, J.W., Coert, J.H., 2013. The incidence of symptomatic neuroma in amputation and neurrhapy patients. J. Plastic Reconstr. Aesthetic Surg. 66, 1330–1334.

Van Grevenhof, E.M., Ott, S., Hazeleger, W., van Weeren, P.R., Bijma, P., Kemp, B., 2011. The effects of housing system and feeding level on the joint-specific prevalence of osteochondrosis in fattening pigs. Livestock Sci. 135, 53–61.

Viitasaari, E., Hänninen, L., Heinonen, M., Raekallio, M., Orro, T., Peltoniemi, O., Valros, A., 2013. Effects of post-partum administration of ketoprofen on sow health and piglet growth. Vet. J. 198, 153–157.

Viitasaari, E., Raekallio, M., Valros, A., Peltoniemi, O., Hänninen, L., Heinonen, M., 2015. The effect of ketoprofen on feeding behaviour of tail-bitten pigs. Porcine Health Manage. 1, 11.

Vinuela-Fernández, I., Jones, E., Welsh, E.M., Fleetwood-Walker, S.M., 2007. Pain mechanisms and their implication for the management of pain in farm and companion animals. Vet. J. 174, 227–239.

Weary, D.M., Braithwaite, L.A., Fraser, D., 1998. Vocal response to pain in piglets. Appl. Anim. Behav. Sci. 56, 161–172.

Weary, D.M., Niel, L., Flower, F.C., Fraser, D., 2006. Identifying and preventing pain in animals. Appl. Anim. Behav. Sci. 100, 64–76.

White, R.G., DeShazer, J.A., Tressler, C.J., Borcher, G.M., Davey, S., Waninge, A, Parkhurst, A.M., Milanuk, M.J., Clemens, E.T., 1995. Vocalisation and physiological response of pigs during castration with or without a local anesthetic. J. Anim. Sci. 73, 381–386.

Wiese, A.J., Yaksh, T.L., 2015. Nociception and pain mechanisms. In: Gaynor, J.S., Muir, W.W. (Eds.), Handbook of Veterinary Pain Management, third ed. Elsevier Mosby, Mossouri, pp. 10–41. In: Gaynor, J.S., Muir, W.W. (Eds.), Handbook of Veterinary Pain Management, third ed. Elsevier Mosby, Mossouri, pp. 10–41.

Woolf, C.J., 1995. Somatic pain – pathogenesis and prevention. Br. J. Anaesth. 75, 169–176.

Woolf, C.J., 2011. Central sensitization: Implications for the diagnosis and treatment of pain. Pain 152, S2–S15.

Woolf, C.J., Doubell, T.P., 1994. The pathophysiology of chronic pain – increased sensitivity to low threshold A-fibre inputs. Curr. Opin. Neurobiol. 4, 525–534.

Woolf, C.J., Mannion, R.J., 1999. Neuropathic pain: aetiology, symptoms, mechanisms and management. Lancet 353, 1959–1964.

Ytrehus, B., Carlson, C.S., Ekman, S., 2007. Etiology and pathogenesis of osteochondrosis. Vet. Pathol. 44, 429–448.

Zimmermann, M., 2001. Pathobiology of neuropathic pain. Eur. J. Pharmacol. 429, 23–37.

On-farm and post-mortem health assessment

12

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12.1 Health and welfare

Health is a very important part of animal welfare and must be properly considered when assessing welfare (FAWC, 1992; Botreau et al., 2007). In fact, health problems are among the most severe welfare problems for farm animals (Scientific Veterinary Committee, 1997). Diseases and injuries may have a negative effect on the emotional state of the animal (through pain and discomfort) and may also interfere with its normal behaviour. Additionally, some diseases provide relevant information on the overall quality of the environment in which the animal lives and this is particularly true for the so-called multifactorial diseases. Some diseases are produced by well-defined primary pathological agents who play by far the most important role in the incidence and severity of the disease. African and Classical Swine Fever and Aujeszky's Disease are examples of those diseases (Straw et al., 2006). In contrast, other types of diseases (i.e., multifactorial diseases) are highly environmentally dependent. The impact of those diseases largely depends on the combination of several management, housing and hygienic conditions of the farm. In multifactorial diseases, the presence of a causative agent is necessary but not sufficient cause for disease. Adrenal activity and the related immunological response that follow difficulties in coping with the environment are shown to reduce the fitness of an individual increasing the incidence of diseases (Broom and Johnson, 1993; Broom, 2006). As mentioned above, multifactorial diseases (Table 12.1) are considered to reflect the overall quality of the environment of the animals; hence, they should be carefully considered within a health assessment system.

12.2 Welfare assessment: environment-based vs animal-based measures

Welfare is multidimensional. It cannot be measured directly and by a single measure; animal welfare science is multidisciplinary (Fraser, 1995) and makes use of a great variety of parameters. These parameters are of two main types: resource/management-based and animal-based measures.

It is possible to assess welfare by looking at the environment of the animals. Resource and management-based measures can indicate if the environment is

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Table 12.1 Main multifactorial diseases and injuries in intensive pig production systems

Multifactorial disease	Multifactorial injury
Porcine respiratory complex (especially growing-fattening period): e.g., PCV2, PRRS viruses, *Mycoplasma hyopneumoniae* and other bacterial agents Gastrointestinal disorders: Bacterial infections (*E. coli*, Salmonella) and non-infectious disorders (especially in weaning and fattening pigs) MMA (sows) Others multifactorial diseases: skin alterations (parasites mange and bacteria)	Lameness (especially in sows) Tail-biting and ear lesions (growing-fattening period) Wounds (sows and weaners)

acceptable for the animals. Much pig legislation is based on environmental-based measures such as space allowance, type of floor, presence of enrichment material, etc. Those indirect measures are based on assumptions concerning the relationships between aspects of the environment and the actual welfare state of the animals. Environmental-based factors are fundamental for the provision of advice on the prevention of a welfare problem and for the detection of a risk of deficient welfare. Information on the risk of welfare problems is particularly important to detect problems whose incidences are rare.

However, many interactions between the environment and the welfare of the animals not always clear (Capdeville and Veissier, 2001). For example, housing (floor type, drinkers, feeders, ventilation system, etc.), management (feeding, hospital pens, etc.), social environment (group vs individual housing, dynamic vs stable group, group size) and human animal relationship are four main types of influencing factors on the prevalence of a welfare problem (outcome) (Waiblinger et al., 2001). In some cases, such as in pain related procedures (tail docking, castration), the link between the management of such procedures (use or not of local anaesthetics and long lasting analgesics) and welfare is confident. In other cases, the relationship between housing, management, human animal relationship and the animal itself (age, immune system, reproductive stage) is complex. The relative importance of each factor on the appearance of a given welfare problem remains difficult to predict especially in a long-term situation. For example, housing animals in groups promotes normal social interactions, but if poorly managed this system can lead to an increased in aggressive interactions (Spoolder et al., 2009). Furthermore, those complex interactions may favour one aspect of welfare but be detrimental for another aspect of welfare. Influencing factors can provide an estimation of the risk of impaired welfare; however the respective impact of those factors is not well understood and is not precise enough to undertake an assessment system based only on those factors.

Instead of measuring the provision of good husbandry, welfare can be measured by observing the animal more directly. Animal-based measures (outcomes) indicate the effect of those indirect environmental-based measures and their interactions on the animal. As welfare is a condition of the animal, animal-based measures are likely to provide the most direct information on its welfare state. Therefore they are generally considered more valid measures of welfare compared to environmental-based measures and should be applicable across production systems. Animal-based measures involve both animal observations and the use of farm records of the animals (Whay et al., 2003) and fall into five main categories: Performance, health, physiology, behaviour and post-mortem measurements.

However, animal-based measures are not free of difficulties, either. The first problem is that they are, sometimes, difficult to interpret. Some animal-based indicators such as injuries (tissue damage) are clearly linked to poor welfare. However, the link between some animal-based indicators – especially behavioural measures of health – with impaired welfare, is not clearly understood. Second, it has to be considered that only a sample of animals is observed. This sample has to be representative of all the animals on the farm which is especially difficult on large farms. A third limitation of most animal-based measures is that recording can be difficult whereas recording of environmental-based measures is quite easy and demands less resources (Bartussek, 2001). Environmental-based measures are also more likely to be repeatable.

Environmental and animal-based measures present both advantages and disadvantages. Consequently, the combination of both types of parameters give the most valid and complete assessment of animal welfare (Johnsen et al., 2001) and, hopefully, enable not only to assess the current welfare state of the animals but also to evaluate potential risks to their welfare.

12.3 On-farm assessment of health

Welfare Quality (WQ) was an integrated research project funded by the European Commission in the sixth framework programme. Forty-four institutes and universities (from thirteen European countries and four Latin American countries) participated in this project which started in 2004 and ended in 2010. One of its main objectives was to develop an integrated standardised methodology for the assessment of welfare in cattle, pigs and poultry on farm and at the slaughterhouse (Blokhuis et al., 2003; Blokhuis, 2008). The WQ assessment system is based on four principles of animal welfare: good housing, good feeding, food health and appropriate behaviour. Each of these four principles includes several criteria, with a total of 12 criteria (Botreau et al., 2007). The WQ principle labelled as 'good health' includes three criteria: absence of injuries, absence of disease and absence of pain induced by management procedure. Still, the health of an animal can be also impaired even though the animal does not apparently suffer from intense stress, injury or disease. WQ protocols for pigs use animal-based measures and were initially developed to be used as farm level assessments and do not include initially any approach to a diagnostic and treatment. Still, those standardised protocols present a first approach for health status assessment that can be completed by further measurements to gain sensitivity.

12.3.1 Performance measures

The accumulation of all attempts to cope with several challenging situations will ultimately affect the animal and thus its performance. It has to be emphasised that good performances do not guarantee an optimised welfare. Examination of performance records can give a first general approximation of the welfare state of the animals on a farm. Performance parameters give an overview of the problems, especially health problems that may experience a herd over time. Their main limitations are their unspecificity which makes them difficult to interpret and their large variability among studies and among countries. Methods of calculation of these parameters can vary between different national recording schemes or commercial software packages (Almond et al., 2006). For that reason their reliability is questionable for farm assessments, especially when used as a certification scheme. Performance measures are especially important when an assessment system is used as an advisory tool or intervention programme. They are essential for the farmer and for the vet practitioner to make a diagnosis. Some examples of commonly used performance parameters are given in Table 12.2. Mortality, excluding culled or active euthanised animals, merely reflects the number of animals becoming so sick

Table 12.2 List of performance parameters and treatment records key indicators for pig farmers and vet practitioners

Growing-finishing pigs	Sows and piglets
• Feed conversion ratio • Average daily gain • Length of fattening period • Number of 'empty days' (number of days between the first pig departure to the slaughterhouse until the last departure) • Average carcass yield • Frequency of antibiotic and/or antinflammatory use during the fattening period • Mortality rate (and possible causes) • Culling rate (and possible causes) • Morbidity of enteric, respiratory and other diseases	• Litter size • Live born per litter • Stillborn per litter • Mummified foetus per litter • Manual interventions per sow during parturition • Total number of treatments per sow around farrowing • Neonatal mortality (until 48−72 h post-farrowing) • Mortality during lactation (from farrowing to weaning) • Number of weaned piglets • Number of underweight weaned piglets • Weaned to farrow interval • Sows mortality rate (and possible causes) • Sow culling rate (and possible causes) • Morbidity of enteric, respiratory and other diseases

that they die prior to slaughter. If two animal husbandry systems are compared and the mortality rate is significantly higher in the first than in the second then we can say that the welfare is less good in the first (Hurnik and Lehman, 1988; Broom, 1991a). Mortality would then be a health indicator. Mortality rate depends on many factors such as the housing system, group size and stockmanship resulting in an unspecific measure unless the causes of death are well known. Poor reproductive performance in sows can be linked to stress situations as well as many other reasons that are not directly related to welfare (oestrus detection, timing of insemination, storage of semen, differences between genetic strains, etc.). Feed conversion ratio (obtained dividing the total feed delivered to each batch by the difference between the total kilograms of pigs sent to slaughter and the total kilograms of pigs that entered at the fattening unit), average daily gain (average g/pig obtain during the fattening period), length of fattening period (total number of days) and number of empty days (number of days between the first pig departure to the slaughterhouse until the last departure) are some measures commonly recorded by fattening pig producers and used as indicators of batch heterogeneity.

12.3.2 Absence of injuries and diseases

The advantage of direct animal-based health indicators is that their link to suffering is clearer, and therefore they are more easily validated than other types of indicators. WQ protocols provide several direct animal-based indicators of the principle 'Good Health' (Table 12.3). In those protocols, 'Good health' measurements are scored at pen or individual level according to a three-point scale ranging from 0 to 2. The assessment scales are selected so that a score 0 is awarded where welfare is good, a score 1 is awarded when applicable and feasible, where there is some compromise on welfare, and a score 2 is awarded where welfare is poor and unacceptable. In some cases, where a condition is either present or absent, a binary (0: absent/2: present) scale is used (Table 12.3). Pigs are individually scored for wounds on the body, tail biting, lameness, pumping (heavy and laboured breathing), twisted snouts, rectal prolapse, skin condition, and hernias. Diarrhoea and coughs and sneezes are evaluated at pen level. Coughs and sneezes are evaluated at pen level considering all the animals that could be seen and controlled from the corridor. To evaluate coughs and sneezes, pigs are forced to stand up and subsequently observed for 5 min (Geers et al., 1989). The number of coughs and sneezes and the number of animal coughing and sneezing are counted. All the other WQ measures of good health are scored from inside the pen as observations carried out from the corridor tended to undervaluate the number of lesions (Coubourlay and Foubert, 2007).

When applied on a large set of commercial farms heterogeneous from a sanitary point of view (based on veterinary records), the majority of direct animal-based health measures proposed by the WQ protocols present very low prevalences and low sensitivity (Temple, 2011; Temple et al., 2012). Such low prevalences make questionable the representativeness of the sampling of animals, especially on big farms. A high percentage of pen and animals should be sampled to generate accurate estimates for those relatively rare parameters. For those rare

Table 12.3 Direct animal-based indicators related to health status provided by the WQ protocols for pigs on farm

Absence of injuries	
For sows and piglets and growing pigs:	lameness assessment
For sows and growing pigs:	wounds on the body
For growing pigs:	tail biting lesions
For sows:	vulva lesions
Absence of diseases	
For sows and piglets and growing pigs:	respiratory problems (coughing, sneezing, pumping)
	enteric problems (rectal prolapse, diarrhea)
For sows and growing pigs:	skin condition
	ruptures and hernias
For sows:	reproductive problems (metritis, mastitis, uterine prolapse)
	enteric problems (constipation)
	abscess
For growing pigs:	respiratory problems (twisted snouts)
For piglets:	neurological problems (muscle tremors, paddling)
	splay leg

parameters, the main issue to be decided is whether we shall consider the average state of the animals on the farm or put more attention on the animals with the worst symptoms. A further limitation of those measures that are individually assessed in a health assessment protocol is their lack of specificity which make them difficult to use in an advisory tool. For example, the variation in the incidence of the parameters 'coughs' and 'sneezes' among farms is difficult to interpret in terms of welfare and neither possible causes of coughs and sneezes nor differences between production systems were detected (Temple et al., 2012). The incidence of coughs and sneezes may vary due to many causes, such as viruses, bacteria, parasites or environmental contaminants (dust, ammonia, etc.) and their incidence can be highly variable from day to day. Combining those signs with other types of measure is necessary to provide more specific information on the presence of respiratory diseases. Studies are needed to assess attitudes of farmers towards the prevention of diseases and to select valid and feasible management-based indicators of health. Evidence of prevention and active management of diseases through health maintenance and monitoring programmes can be of special interest to increase our interpretation of health outcomes (Main et al., 2001). Stockpersons routinely gather auditory, olfactory and visual information from their animals to evaluate health, welfare and productivity and further emphasis should be given to those collected data.

12.3.2.1 Assessment of wounds on the body (on farm)

Wounds on the body mainly originate by three types of causes: (1) fights between animals, (2) inappropriate design of facilities, and (3) handling. Some types of round and/or deep wounds can be caused by infections. Wounds can vary in terms of number of lesions, nature (scratches, opened lesion, abrasion), size, depth and state of healing (fresh wounds or old scars) (Velarde, 2007). The localisation of the wounds is also very important (head/ears/neck, shoulders, back and hind-quarters) as it will help to ascertain their possible causes. Marks due to biting during fights are scratches of 5−10 cm long in a comma shape, numerous and concentrated in a specific area. Lesions on the head, ear and shoulders are usually caused by social ranking establishment. Wounds on the hind part of the body are caused by competition for food (Leeb et al., 2001), mounting, or by rough handling. Ear wounds can be caused by bacterial infections (ear necrosis) or ear biting. The WQ protocol for pigs proposed the following methodology to assess wounds on the body. Pigs are encouraged to stand up to make the body clearly visible. One side of the pig's body is inspected visually for the presence of lesions and/or penetration of the muscle tissue, considering five separate zones: (1) ears, (2) front (head to back of shoulder), (3) middle (back of shoulder to hind-quarters), (4) hind-quarters, (5) legs (from the accessory digit upwards). The tail zone is not considered here. Lesions are valued on a point scale, according to their severity. Each scratch longer than 2 cm as well as a round lesion smaller than 2 cm is given 1 point. A round lesion from 2 to 5 cm of diameter or more than 5 cm and healed is given five points. A round lesion of more than 5 cm, deep and opened is equal of 16 points (Fig. 12.2). Points are summed across each zone separately. Animals are considered not wounded when all zones have below five points; as moderately wounded animals when at least one zone has five or more points but not more than one zone is over 11 points and no zone is over 15; and as severely wounded animals when two or more body zones are over 11 or any zone is over 15.

Applying this methodology, Scott et al. (2009) reported prevalences of 12% and 2% of moderately and severely wounded sows, respectively. Temple et al. (2012) reported an average prevalence of 2.5% of severely wounded animals when assessing more than 60 intensive farms on slatted floor. Twenty-four hours post-weaning, Temple et al. (2016) reported prevalences of 21% and 9% of moderately and severely wounded piglets (see Figs. 12.1−12.3).

12.3.2.2 Assessment of tail biting (on farm)

The area of the tail is considered as another parameter, as lesions on the tail may be indicative of tail biting. It has been shown that tail biting is caused by a range of welfare challenges pigs might encounter (Valros, Chapter 5: Tail biting). Lack of proper enrichment material is one of the main risk factors; however, other important factors can lead to an outbreak of tail biting. Situations of competition/frustration (e.g., restricted access to food or water), and stress (e.g., thermal stress) enhance the incidence of tail biting (Taylor et al., 2010) (see also Fig. 12.4). Tail biting is a

Figure 12.1 Gestating sow with scratches on the shoulder area.

Figure 12.2 Growing Iberian pig with a deep wound.

multifactorial problem involving factors specific of the animal (genetics, sex, age, health status) as well as management (e.g., feeding management) and environmental factors (absence of material suitable enrichment, unbalanced diet, high densities, malfunctioning drinkers, etc.).

Tail biting has been used to describe a wide range of behaviours and lesions. Tail biting can be observed through behavioural observations, however this method would require long and detailed period of observations as the behaviour is very sporadic. On the other hand, the scoring of tail lesions especially the more severe cases can be recorded with a relatively high level of feasibility, repeatability and validity (Bracke, 2007). Zonderland et al. (2003) presented a detailed scoring method to assess tail-biting lesion according to three criteria: tail length, tail injuries and

Figure 12.3 Severely wounded pig at the weaning period.

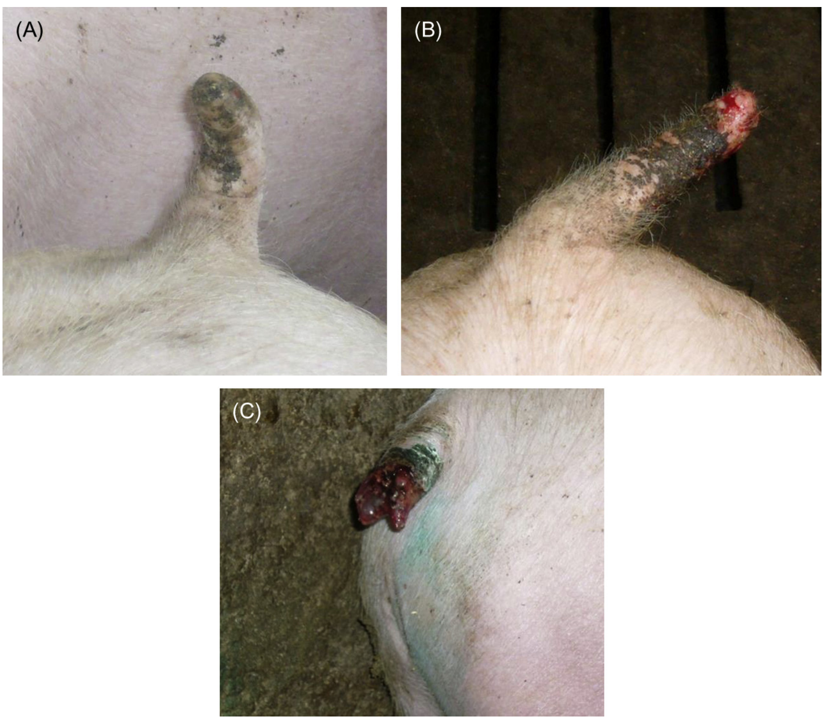

Figure 12.4 WQ simple scoring system for tail-biting lesions. (A) No sign of blood, (B) severe tail-biting lesion, (C) fresh blood or crust visible.

blood. This type of scoring method can provide many information on the nature of tail biting being sensitive to detect any tail biting on a farm; however, such detailed scoring scales may lose feasibility and repeatability when applied on commercial farms. At expenses of throwing away information, recording only severe cases of tail lesions as present (any hint of fresh blood, crust or necrosis of the tail) or absence is indeed much more simple when used on a farm assessment. Tail-biting lesions are generally recorded as the proportion of tail-bitten pigs in a given population, but sometimes refers to the proportion of pens or farms experiencing the problem.

When evaluating severe tail-biting cases on commercial farms in France and Spain, Temple et al. (2012) reported a prevalence of 1.2% severe cases of tail lesions in pigs on concrete floors and 1.4% in pigs on straw. Hospital pens were not considered in the sampling. The detection of any severe case of tail lesion in normal pens can be considered as a welfare concern.

12.3.2.3 Newly proposed indicators to assess diseases

Finding new and easy to use indicators to assess animal health on farm is necessary. Telkänranta et al. (2016) proposed a first evaluation of feasibility and validity of tear staining in pigs under commercial farming conditions. Tear staining could be a promising indicator for pig welfare assessment. Tear staining is described as brown to black facial stains in and below the inner corner of the eye (McCafferty and Pinkstaff, 1970). It has been used as an indicator of atrophic rhinitis (OIE, 2012), as a measure of clinical disease and poor air quality (Whay et al., 2007; Wright, 2012) and as a sign of chronic stress (DeBoer SP and Marchant-Forde, 2013; DeBoer et al., 2015; Telkänranta et al., 2016). Detection of 'runt' pigs is usually used by vets to detect sick animals. Prevalence of 'runt' animals can be high in some farms with acute infection. The detection of inactive animals with a low body condition and scruffy hair coat can be a selective indicator of the fever reaction caused by an active infection (Hart, 2010).

12.3.3 Behavioural and physiological changes linked to poor health

While clinical signs of a pathology are clear indicators of poor welfare, the health (and therefore the welfare) of an individual can be also impaired even though it does not apparently suffer from stress, injury or disease (Broom, 1991b). When health indicators lack of sensitivity, the evaluation of welfare should rely on physiological and behavioural changes.

12.3.3.1 Behavioural indicators of poor health

Behaviour becomes essential as an indicator of health problems. Alteration in the frequencies of normal behaviour and the occurrence of abnormal behaviours are possible indicators of health problems. Behaviours clearly indicate poor welfare when associated with physical suffering. Behaviour is commonly used in the clinical assessment of health and particularly of pain, and changes in behaviour brought about by disease are used by veterinarians in the diagnosis of disease (Broom, 1987; Fraser and Broom, 1990). Detection of behavioural changes is particularly important in subclinical diagnosis and thereafter in the prevention and control of pathologies. Examples of behaviour indicating pain in pigs include reluctance to move and a lack of normal social behaviour (Fraser and Broom, 1990). These and other signs of pain, whether related to diseases or injuries, have been considered in detail by several authors (e.g., Houpt and Wolski, 1982; Straw et al., 2006; Herskin and Di Giminiani, Chapter 11: Pain in pigs: Characterisation, mechanisms and indicators); however the inclusion in a health assessment tool has been limited. One of the bigger limitation of behavioural indicators to be used in a assessment tool is their low repeatability between observers. A study on the validity of sickness behaviour in dairy calves has proposed to integrate behavioural tools such as lethargy score, standing motionless and less willingness to approach the observer as predictors of disease (Stanton et al., 2011). Similar behavioural indicators of 'sickness' may increase the selectivity (and probably the sensitivity) of health measures in pigs and should be of interest in further studies. Scales to evaluate more subtle signs of pain based on behavioural changes have been validated (Dobromylskyj et al., 2000). Mainau et al. (2010), for instance, developed an ease of farrowing score in sows kept in farrowing crates based on the behaviour of the sows and their piglets.

Precision Livestock Farming (PLF) technology has a big potential to promote and generate behavioural indicators for pig health. Sounds produced by pigs can be monitored and analysed to assess animal health status (Van Hirtum and Berckmans, 2004). For example, 'Coughing' detected and monitored through PLF technologies can be translated into a health indicator (Pig cough monitor). Technological and biotechnological innovation in automated health diagnostics is being developed and represents a huge step forward in health monitoring.

12.3.3.2 Physiological indicators of poor health

Despite their lack of feasibility, physiological indicators of poor health may increase the sensitivity of a health assessment tool. The acute phase proteins (APPs) are a group of blood proteins that change in concentration in animals that are subjected to external or internal challenges, such as infection, inflammation, surgical trauma and stress (Murata et al., 2004). The C-reactive protein (CRP) and haptoglobin (Hp) are two APPs that change concentrations considerably upon inflammatory stimulus (Cray et al., 2009). Concentrations of CRP and Hp are related to the severity of underlying diseases (Eckersall, 2000). In apparently healthy pigs, Pallarés et al. (2008) found serum levels of Hp and CRP significantly higher in animals with lesions at slaughter than those without lesions. Geers et al. (2003) found a relation between Hp level at slaughter on the one hand and management, housing conditions, and health during fattening on the other hand. Destexhe et al. (2013) showed that CRP can be used as a biomarker of acute inflammation 1 day after vaccine administration. However, it may be difficult to distinguish an increase of APP caused by the activation of the HPA axis (stress response) from an increase of APP due to a latent infection or inflammation. Levels of APPs should therefore be interpreted together with prevalence of health problems and performance indicators. Recently, Stavrakakis et al. (2016) proposed serum biomarkers of cartilage synthesis and degradation, respectively collagen II propeptide and collagen II cleavage product, as promising tools for lameness diagnosis in growing pigs.

12.3.4 Absence of pain induced by management procedures

In intensive pig production systems, teeth resection, tail docking and castration are painful and routinely applied management practices (Prunier et al., 2005; Marchant-Forde et al., 2009). These management practices are often made in young piglets without analgesia or anaesthesia; however, several scientific studies clearly demonstrate that neonates perceive pain.

Piglets are neurologically mature newborns similar to lambs, kids, bovine calves and human infants (Ellingson and Rose, 1970; Mellor and Stafford, 2004). Most published information on foetal and neonatal pain refers to lambs and human infants, but sufficient is known about the other species for some cautious inferences to be made about them as well. Such newborn mature animals usually become conscious within the first few minutes to hours after birth (Mellor and Gregory, 2003). Once consciousness appears, the newborn will be able to experience pain and suffering. Evidence on the difference between neonates and adults in pain sensitivity are contradictory. Some studies suggest that the descending central inhibitory pathways and interneurons that modulate nociceptive inputs in the spinal cord may be relatively immature at birth (Fitzgerald and Koltzenburg, 1986). Neonates may therefore be more sensitive to noxious stimuli than older animals. Other recent studies speculated that several hormonal factors with anaesthetic, sedative and analgesic properties that are synthetised before birth by the foetal brain may carry over into the postnatal period (Mellor and Diesch, 2006; Baxter and Edwards, Chapter 3: Piglet mortality and morbidity: inevitable or unacceptable?). This would suggest that during the first few days after birth, the young may be less sensitive to painful stimuli.

Independent of whether or not there is a difference between younger and older animals in experiencing pain, there is not doubt that piglets suffer during invasive procedures such as teeth resection, tail docking and castration. It should also be emphasised that neonatal pain can lead to long-term changes in pain behaviours that persist as the animal ages.

Knowing that teeth resection, tail docking and castration are painful management practices, justification of those mutilations is widely questionable. Teeth are resected to prevent lesions on the udder of the sow and on the faces of littermates. Moreover it is often practiced to prevent secondary infections due to fights at weaning. Although resection can protect littermates from damage, it may increase internal mouth lesions in piglets with resected teeth (Lewis et al., 2005) and result in pulpitis (Hay et al., 2003). Teeth resection should not be undertaken on a routinar basis and without weighing the benefits and the cost of such practice.

Tail docking is utilised to avoid tail biting which is an harmful redirected behaviour towards penmates. However, prevention of tail biting should be based on an multifactorial approach of the problem including improvement in the health status, housing and management conditions of the animals. Welfare assessment protocols should therefore penalised when tail docking is used inappropriately as a single treatment to prevent tail biting.

Castration in pigs is justified by the improved quality of the final product (which prevents the incidence of boar taint). General or local anaesthesia allows for reducing the pain during and immediately after the castration, while the administration of a long-action analgesia only reduces the pain after the surgery. Therefore, both products must be combined to be effective in minimising pain caused by surgical castration. According to expert opinion and scientific evidence, there is no recognised feasible and effective method to date to minimise acute and chronic pain associated with surgical castration in pigs (De Bryine et al., 2016). Besides practical limitations, the use of anaesthesia remains a big constraint. Immunocastration and entire males production are two alternatives to pig castration (Prunier et al., 2006).

12.3.5 Treatment of sick animals and euthanasia

Inappropriate management of sick animals is a very common cause of suffering. The evaluation of the management of hospital pens and euthanasia criteria should be well considered in a health assessment protocol.

Sick animals should be efficiently detected and identified. Any pig that cannot care for himself, whether due to an injury (e.g., severe lameness, severe tail biting, hernia), or a disease, must be taken to an hospital pen immediately. Hospital pens should be prioritised for sick animals and should not house healthy pigs (see Table 12.4). Sick animals should be monitored and treated if necessary. If the animal does not respond to a treatment, the treatment should be changed. If the animal becomes very sick, it should be euthanised.

Table 12.4 Possible scoring scale for the assessment of management of sick animals

Management of sick animals
Hospital pens No welfare concern = pens for sick animal and they are used correctly (only sick animals) Moderate welfare concern = pens for sick animals but most of them are used for slow growing animals Severe welfare concern = no pens for sick animals (ex. Only passageways, or nothing)
Presence of sick animals
No welfare concern = absence of sick animals in normal pens Severe welfare concern = presence of sick animals in normal pens

Table 12.5 Common causes of severe injuries where pigs should be euthanised

Sows
• Uterine prolapse
• Rectal stenosis
• Severe lameness (e.g., hindquarter down; severe infections of articulations with no response to treatments)
• Broken bones
Growing-fattening pigs
• Severe lameness (e.g., hindquarter down; severe infections of articulations with no response to treatments)
• Broken bones
• Tail with sever abscess and necrosis
• Severe rectal prolapse

Hospital pens should have a comfortable resting place and prevent thermal stress. Water and food should be provided ad libitum, providing easy access for the animal. The floor, water trough and hopper should be cleaned. There should be enough space per animal in the hospital pen (growing pig: $>1\ m^2$; sow: $>3\ m^2$). To ease the supervision of the animals, hospital pens should be well illuminated.

Three main criteria may help to decide on whether or not an animal should be euthanised (see also Faucitano and Goumon, Chapter 9: Transport of pigs to slaughter and associated handling):

- When an animal is suffering severely or when treatment is unsuccessful.
- When an animal can originate in a disease outbreak.
- When an animal is growing too slowly and will not reach slaughter weight.

Table 12.5 shows causes of severe injuries where pigs should be euthanised on farm. Once decided, euthanasia should be done properly. Generally, veterinarians do not perform euthanasia on farm routinely. Euthanasia becomes the producer's responsibility. The latter should therefore be informed of humane methods of euthanasia. Method of euthanasia has to be safe for the producer and should not produce pain or distress to the animal. The producer should be trained and the method of euthanasia should be appropriate according to the age of the pig. Piglets of less than 5 kg are usually euthanised by a shock on the skull. Piglets from 5 to 32 kg, growing-finishing pigs, boars and sows are generally euthanised by applying a penetrating captive bolt by the producer. Both methods can be emotionally difficult to undertake.

12.4 Assessment of health at the abattoir

Different points in the slaughterhouse must be considered in a full monitoring system to assess pig welfare. As transportation is considered a major stressor for farm animals, especially for pigs (Faucitano and Goumon, Chapter 9: Transport of pigs to slaughter and associated handling), and might have detrimental effects on the health, well-being, performance and meat quality the unloading area is an important point to consider (Velarde and Dalmau, Chapter 10: Slaughter of pigs). Welfare in the lairage area is also related to health issues and should also be assessed. Stunning effectiveness is a major issue to consider and assess, as an inappropriate stunning will produce pain and suffering (Velarde and Dalmau, Chapter 10: Slaughter of pigs). Finally, postslaughter indicators taken on the carcass are essential to evaluate the health status of the animals in the farm of origin and are considered in this chapter.

Post-mortem inspection of slaughtered pigs at abattoirs is performed for every individual. Data relating to animal health are routinely collected at meat inspection levels primarily for public health protection but the same data could be used to assess animal health (Sanchez-Vazquez et al., 2011). A survey to pig producers asking opinion on post-mortem welfare assessment, most respondents recognised the benefit of the utilisation of MI data as a health and welfare diagnostic tool (Devitt et al., 2016). The inspection at the abattoir could be used to assess health on farm, at market and during transport by direct observation using ante- and post-mortem measures to benchmark the prevalence of health indicators of welfare (Pointon et al., 1999; Llonch et al., 2015). Abattoir meat inspection has several advantages over farm-based inspections for the collection of data relating to animal-based welfare outcomes (Harley et al., 2012). For example, meat inspection might be used as a 'cheap diagnostic tool' in health surveillance based on animal-based measures which are the preferred variables for animal welfare assessment (Cleveland-Nielsen et al., 2004). The availability of meat inspection data has been extensively used in epidemiological studies investigating the occurrence of common lesions such as pneumonia and pleurisy abscessation, ascariasis and tail-biting injuries (Harley et al., 2012).

Improving animal health surveillance and the identification of simple and reliable indicators of animal health are priorities in the current agenda of the EU on animal health strategy (Sanchez-Vazquez et al., 2011). The implementation of effective health assessment programs in abattoirs requires measures that are feasible, valid and repeatable to enable comparisons across different husbandry systems (Dalmau et al., 2009). Current research is focused on developing new post-mortem indicators of welfare (Brandt et al., 2013), and at the same time improving the feasibility of assessment of established measures (Carroll et al., 2016). A selection of measures to assess the prior health status of pigs have been proven to comply with the previous requirements through the inspection of carcasses and the internal organs.

The integument is one of the first organs that can be assessed in meat inspection of pigs. Damage of the integument can be caused by physical or chemical means. Physical damage includes interactions with conspecifics (e.g., aggression and tail biting), inadequate handling of animals and abrasion or collision with physical structures (e.g., slatted doors). The presence of skin lesions such as dried blood and an open sore in recent injuries to hyperkeratosis or hairless patches in older lesions are signs of skin lesions that can be monitored post-mortem (Dalmau et al., 2009).

Skin lesions on the rear part of the body may be caused by rough handling, while skin lesions on the frontal part of the body may often be caused as a result of fighting between pigs (Dalmau et al., 2014). Tail damage can also be reported during meat inspection according to Keeling et al. (2012). A six grade scale to monitor tail damage at the carcass was found to be reliable as a method to identify problem at farms, however considering only fresh lesions underestimates the prevalence of tail damage. To amend this, Keeling et al. (2012) proposed that a three-grade scale including both old and new tail damage would be more appropriate. Beside integument insults, reliable data on mutilations such as tail docking can be recorded through carcass inspections (Harley et al., 2012).

Pig digestive disorders have been extensively studied as they impact both health and performance. Diarrhoea is the main symptom of gastrointestinal disease which is potentially detectable during carcass inspection before processing, but the identification of the causing pathogen may be impossible unless additional analysis are performed. On the contrary, some parasitic infections may often be possible to detect by visual inspection. For example, the BPEX (British Pig Executive) Pig Health Scheme (BPHS) monitors the prevalence of ascariosis (*Ascaris suum*) in slaughtered finished pigs by identifying milk spots – the healing lesions caused by larvae migration through the liver (Sanchez-Vazquez et al., 2012). Dalmau et al. (2009) suggest the use of white spots on the liver as an indicator of health, probably referring to *A. suum* infections, which can be monitored during carcass processing at the abattoir. Another reported gastrointestinal health problem that can be monitored in abattoirs is the presence of oesophagogastric ulceration in pigs (Penny and Hill, 1973). A recent study conducted in the United Kingdom abattoirs found that the frequency of pigs with severe oesophagogastric ulceration was 6.4% (Swaby and Gregory, 2012). Stress is thought to be implicated in the formation of gastric ulcers, and exacerbated by feeding regimes increasing exposure of the mucosa of the pars oesophagea to acidic conditions (Straw et al. 2006). Although stomach examination is not part of the present meat inspection scheme, the inclusion of severe gastric ulcers in surveillance programs would be suitable as they are a measure of health but also reflects some of the standards of handling and husbandry which relate to stress (Friendship, 1999).

For post-mortem health assessment of the respiratory system, Dalmau et al. (2009) used the presence of pleurisy and pneumonia in the lungs. As in liver surveillance, the lung is routinely assessed at post-mortem meat inspection by identification of macroscopic lesions that may result in organ trimming or condemnation. The lung lesion type and severity have been developed as indicators of respiratory diseases in pigs (Welfare Quality, 2009). The lesions more frequently detected are pleurisy (fibrosis of pleural membrane), pneumonia (plum-coloured consolidation of lung parenchyma) and abscessation (focal encapsulated yellow–green lesion protruding from lung parenchyma) (Dalmau et al., 2009; Teixeira et al., 2016).

The heart is also a targeted organ during meat inspection. Heart pericarditis, defined as a fibrosis of the pericardial sac, with or without fluid, is also routinely monitored during meat inspection and its presence may result in condemnation as it is considered an aesthetic defect but harmless. However, in regards to animal health, it may be associated with certain swine-specific generalised infections with, for example, *Haemophilus parasuis* and mycoplasmal infections (Mousing et al., 1997; Jensen et al., 1995), and therefore its presence may be indicative of illness. Pericarditis have already been suggested as a post-mortem indicator of pig health in several studies (Dalmau et al., 2009; Teixeira et al., 2016).

Lameness of sows is a health problem frequently encountered in many swine herds resulting in pain and decreased animal welfare (Anil et al., 2005). Lameness can be assessed post-mortem by examining the claw before being removed from the carcass. Dewey et al. (1993) performed a clinical and post-mortem examination of claws from culled sows and found that the primary cause of lameness was usually evident. Therefore a systematic foot examination and comparing all feet for subtle abnormalities and deformities can be used to monitor lameness in breeding sows. For example, Heinonen et al. (2006) estimated the degree of lameness in sows with different diagnoses and saw that mild lameness was associated with symptoms of osteochondrosis or osteoarthrosis, claw lesions or overgrown claws, whereas severely lame sows had more arthritis, infected skin wounds or infected claw lesions.

Illness is often associated with a decrease in performance which can be translated into a reduction of body condition and weight. Carcass classification must be performed in Europe according to the Commission Regulation No 1249/2008. Carcasses must be classified according to their shape and volume of muscle in relation to bone structure in a grading from 1 (very thin) to 5 (very fat) which may be associated with body condition. Nevertheless, the relationship between live BCS (Body Condition Score) and dead carcass classification has not yet been properly studied and this is an important area for future research (Llonch et al., 2015). On the other hand, carcass weight has already been associated with health problems as detected at the abattoir. For instance, Teixeira et al. (2016) found that tail lesion score, pleurisy, pleuropneumonia, and pericarditis were associated with reductions in carcass cold weight. Although it may not be relevant as an independent variable, together with other variables, this can help detect diseases that have an impact on the general health of pigs.

There are still some health problems that are not being monitored in routine meat inspection as they are not considered to be a threat for human health. This is for example the case of diseases affecting the reproductive system, with special emphasis for sows. There are examples of other species where reproductive health can be monitored at the abattoir. Napolitano et al. (2011) suggest the use of vulvar discharge as an indicator of compromised health in sheep. The development of indicators covering these gaps is strongly encouraged as if valid and reliable indicators of all systems are present this may allow an integrated assessment of pig health.

12.5 Future trends

Methods for animal welfare assessment are in constant evolution, increasing the collection ease and validity of animal welfare measures. The combination of on farm and at slaughter welfare assessment is fundamental to achieve a complete health assessment. The so-called 'Precision Livestock Farming' concept integrates computing and sensing technologies that allows the recording of numerous behavioural, physiological and metabolic data in livestock species. Additionally, experience from our own research and that of colleagues shows the development of new animal-based measures of welfare that can be routinely assessed in an extensive range of contexts. The validation of indicators that can be used during meat inspection to assess health and other related issues is a good example of this. The expertise of vet pig practitioners and producers should be integrated with pig welfare research in order to improve the health of the animals. Therefore, knowledge exchange platforms that include the main actors in the pig production chain will be of paramount importance.

Abbreviations

APP acute phase proteins
CRP C-reactive protein
MMA mastitis–metristis–agalactia
PCV2 porcine circovirus 2
PLF precision livestock farming
PRRS porcine reproductive and respiratory syndrome
WQ Welfare Quality

References

Almond, G.W., Flowers, W.L., Batista, L., D'Allaire, S., 2006. Diseases of the reproductive system. In: Straw, B.E., Zimmerman, J.J., D'Allaire, S., Taylor, D.J. (Eds.), Diseases of Swine. Blackwell Publishing, Iowa, USA, pp. 113–147.

Anil, S.S., Anil, L., Deen, J., 2005. Evaluation of patterns of removal and associations among culling because of lameness and sow productivity traits in swine breeding herds. J. Am. Vet. Med. Assoc. 226, 956–961.

Bartussek, H., 2001. An historical account of the development of the animal needs index ANI-35L as part of the attempt to promote and regulate farm animal welfare in Austria: an example of the interaction between animal welfare science and society. Acta Agric. Scand. Sect. A: Anim. Sci. 51, 34–41.

Baxter, E.M., Edwards, S.A., 2017. Piglet mortality and morbidity: inevitable or unacceptable? In: Špinka, M. (Ed.), Advances in Pig Welfare. Woodhead Publishing, Duxford, UK.

Blokhuis, H.J., 2008. International cooperation in animal welfare: the Welfare Quality® project. Acta Agric. Scand. Sect. A: Anim. Sci. 51, 1–5.

Blokhuis, H.J., Jones, R.B., Geers, R., Miele, M., Veissier, I., 2003. Measuring and monitoring animal welfare: transparency in the food product quality chain. Anim. Welfare. 12, 445–455.

Botreau, R., Bracke, M.B.M., Perny, P., Butterworth, A., Capdeville, J., Van Reenen, C.G., Veissier, I., 2007. Definition of criteria for overall assessment of animal welfare. Anim. Welfare. 16, 225–228.

Bracke, M., 2007. Tail biting, ear biting and cannibalism. In: Geers, R., Velarde, A. (Eds.), On Farm Monitoring of Pig Welfare. Wageningen Academic Publishers, Wageningen, The Netherlands, pp. 57−64.

Brandt, P., Rousing, T., Herskin, M.S., Aaslyng, M.D., 2013. Identification of post-mortem indicators of welfare of finishing pigs on the day of slaughter. Livest. Sci. 157, 535−544.

Broom, D.M., 1987. The veterinary relevance of farm animal ethology. Vet. Rec. 121, 400−402.

Broom, D.M., 1991a. Assessing welfare and suffering. Behav. Process. 25, 117−123.

Broom, D.M., 1991b. Animal welfare. Concepts and measurements. J. Anim. Sci. 69, 4167−4175.

Broom, D.M., 2006. Behaviour and welfare in -relation to pathology. Appl. Anim. Behav. Sci. 97, 73−83.

Broom, D.M., Johnson, K.G., 1993. Stress and Animal Welfare. Chapman and Hall, London, UK.

Capdeville, J., Veissier, I., 2001. A method of assessing welfare in loose housed dairy cows at farm level, focusing on animal observations. Acta Agric. Scand. Sect. A: Anim. Sci. 51, 62−68.

Carroll, G.A., Boyle, L.A., Teixeira, D.L., van Staaveren, N., Hanlon, A., O'Connell, N.E., 2016. Effects of scalding and dehairing of pig carcasses at abattoirs on the visibility of welfare-related lesions. Animal 10, 460−467.

Cleveland-Nielsen, A., Christensen, G., Ersbøll, A.K., 2004. Prevalences of welfare-related lesions at post-mortem meat-inspection in Danish sows. Prev. Vet. Med. 64, 123−131.

Commission Regulation (EC) No. 1249, 2008. Laying down detailed rules on the implementation of the community scales for the classification of beef, pig and sheep carcases and the reporting of prices thereof.

Courboulay, V., Foubert, C., 2007. Testing different methods to evaluate pig welfare on farm. Anim. Welfare 16, 193−196.

Cray, C., Zaias, J., Altman, N.H., 2009. Acute phase response in animals: a review. Comp. Med. 59, 517−526.

Dalmau, A., Temple, D., Rodríguez, P., Llonch, P., Velarde, A., 2009. Application of the Welfare Quality® protocol at pig slaughterhouses. Anim. Welfare 18, 497−505.

Dalmau, A., Fabrega, E., Manteca, X., Velarde, A., 2014. Health and welfare management of pigs based on slaughter line records. J. Dairy Vet. Anim. Res. 1, 16. Available from: http://dx.doi.org/10.15406/jdvar.2014.01.00016.

De Bryine, N., Berg, C., Blaha, T., Temple, D., 2016. Pig castration: will the EU manage to ban pig castration by 2018? Porcine Health Manag. J. 2, 29, http://dx.doi.org/10.1186/s40813-016-0046-x.

DeBoer, S.P., Marchant-Forde, J.N., 2013. Tear staining as a potential welfare indicator in pigs. In: Proceedings of the 47th Congress of the International Society for Applied Ethology, Florianopolis, Brazil, p. 125.

DeBoer, S.P., Garner, J.P., McCain, R.R., Lay Jr, D.C., Eicher, S.D., Marchant-Forde, J.N., 2015. An initial investigation into the effects of social isolation and enrichment on the welfare of laboratory pigs housed in the PigTurn system, assessed using tear staining, behaviour, physiology and haematology. Anim. Welfare 24, 15−27.

Destexhe, E., Prinsen, M.K., van Schöll, I., Kuper, C.F., Garçon, N., Veenstra, S., Segal, L., 2013. Evaluation of C-reactive protein as an inflammatory biomarker in rabbits for vaccine nonclinical safety studies. J. Pharmacol. Toxicol. Methods 68, 367−373.

Devitt, C., Boyle, L., Teixeira, D.L., O'Conell, N.E., Hawe, M., Hanlon, A., 2016. Pig producer perspectives on the use of meat inspection as an animal health and welfare diagnostic tool in the Republic of Ireland and Northern Ireland. Irish Vet. J. 2016, 69.

Dewey, C.E., Friendship, R.M., Wilson, M.R., 1993. Clinical and post-mortem examination of sows culled for lameness. Can. Vet. J. 34, 555−556.

Dobromylskyj, P., Flecknell, P.A., Lascelles, B.D., Livingston, A., Taylor, P., Waterman-Pearson, A., 2000. Pain assessment. In: Flecknell, P.A., Waterman-Pearson, A. (Eds.), Pain Management in Animals. Harcourt Publishers, London, UK, pp. 53−79.

Eckersall, P.D., 2000. Acute phase proteins as markers of infection and inflammation: monitoring animal health, animal welfare and food safety. Ir. Vet. J. 53, 307−311.

Ellingson, R.J., Rose, G.H., 1970. Ontogenesis of the electroencephalogram. In: Himwich, W.A. (Ed.), Developmental Neurobiology. W.A. Charles C Thomas Publisher, Springfield, IL, USA, pp. 441−474.

Faucitano, L., Goumon, S., 2017. Transport of pigs to slaughter and associated handling. In: Špinka, M. (Ed.), Advances in Pig Welfare. Woodhead Publishing, Duxford, UK.

FAWC, 1992. Farm animal welfare council updates the five freedoms. Vet. Rec. 17, 357.

Fitzgerald, M., Koltzenburg, M., 1986. The functional development of descending inhibitory pathways in dorsolateral funiculus of the newborn rat spinal cord. Dev. Brain Res. 24, 261−270.

Fraser, A.F., Broom, D.M., 1990. Farm Animal Behaviour and Welfare. Baillière Tindall, London, UK.

Fraser, D., 1995. Science, values and animal welfare: exploring the 'inextricable connection'. Anim. Welfare 4, 103−117.

Friendship, R., 1999. Gastric ulcers. In: Straw, B.E., D'Allaire, S., Mengeling, W.L., Taylor, D.J. (Eds.), Diseases of Swine, eight Ed. Blackwell Science, Oxford, UK, p. 1209.

Geers, R., Dellaert, B., Goedseels, V., Hoogerbrugge, A., Vranken, E., Maes, F., Berckmans, D., 1989. An assessment of optimal air temperatures in pig houses by the quantification of behavioural and health-related problems. Anim. Prod. 48, 571−578.

Geers, R., Petersen, B., Huysmans, K., Knura-Deszczka, S., De Becker, M., Gymnich, S., Henot, D., Hiss, S., Sauerwein, H., 2003. On-farm monitoring of pig welfare by assessment of housing, management, health records and plasma haptoglobin. Anim. Welfare 12, 643−647.

Harley, S., More, S., O'connell, N., Hanlon, A., Teixeira, D., Boyle, L., 2012. Evaluating the prevalence of tail biting and carcase condemnations in slaughter pigs in the Republic and Northern Ireland, and the potential of abattoir meat inspection as a welfare surveillance tool. Vet. Rec. 171, 621−721.

Hart, B.L., 2010. Beyond fever: comparative perspectives on sickness behavior. In: Breed, M.D., Moore, J. (Eds.), Encyclopedia of Animal Behavior. Academic Press, Oxford, UK, pp. 205−210.

Hay, M., Vulin, A., Genin, S., Sales, P., Prunier, A., 2003. Assessment of pain induced by castration in piglets: behavioural and physiological responses over the subsequent 5 days. Appl. Anim. Behav. Sci. 82, 201−218.

Heinonen, M., Oravainen, J., Orro, T., Seppa-Lassila, L., Ala-Kurikka, E., Virolainen, J.V., Tast, A., Peltoniemi, O.A.T., 2006. Lameness and fertility of sows and gilts in randomly selected loose-housed herds in Finland. Vet. Rec. 159, 383−387.

Herskin, M.S., Di Giminiani, P., 2017. Pain in pigs: characterisation, mechanisms and indicators. In: Špinka, M. (Ed.), Advances in Pig Welfare. Woodhead Publishing, Duxford, UK.

Houpt, K.A., Wolski, T.R., 1982. Domestic Animal Behaviour for Veterinarians and Animal Science. Iowa State University Press, Iowa, USA.

Hurnik, J.F., Lehman, H., 1988. Ethics and farm animal welfare. J. Agric. Environ. Ethics 1, 305−318.

Jensen, T.K., Aalbaek, B., Buttenschon, J., Friis, N., Kyrval, J., Ronsholt, L., 1995. Mycoplasma hyopneumoniae and mycoplasma hyosynoviae infection in cases of fibrinous pericarditis in slaughter pigs. Acta Vet. Scand. 36, 575.

Johnsen, P.F., Johannesson, T., Sandøe, P., 2001. Assessment of farm animal welfare at herd level: many goals, many methods. Acta Agric. Scand. Sect. A: Anim. Sci. 51, 26–33.

Keeling, L.J., Wallenbeck, A., Larsen, A., Holmgren, N., 2012. Scoring tail damage in pigs: an evaluation based on recordings at Swedish slaughterhouses. Acta Vet. Scand. 54, 1.

Leeb, B., Leeb, C., Troxler, J., Schuh, M., 2001. Skin lesions and callosities in group-housed pregnant sows: animal-related welfare indicators. Acta Agric. Scand. Sect. A. 30, 82–87.

Lewis, E., Boyle, L.A., Brophy, P., O'Doherty, J.V., Lynch, P.B., 2005. The effect of two piglet teeth resection procedures on the welfare of sows in farrowing crates. Part 2. Appl. Anim. Behav. Sci. 90, 251–264.

Llonch, P., King, E.M., Clarke, K.A., Downes, J.M., Green, L.E., 2015. A systematic review of animal based indicators of sheep welfare on farm, at market and during transport, and qualitative appraisal of their validity and feasibility for use in UK abattoirs. Vet. J. 206, 289–297.

Main, D.C.J., Webster, A.J.F., Green, L.E., 2001. Animal welfare assessment in farm assurance schemes. Acta Agric. Scand. Sect. A: Anim. Sci. 51, 108–113.

Mainau, E., Dalmau, A., Ruiz de la Torre, J.L., Manteca, X., 2010. A behavioural scale to measure ease of farrowing in sows. Theriogenology 74, 1279–1287.

Marchant-Forde, J.N., Lay, D.C., Mc Munn, K.A., Cheng, H.W., Pajor, E.A., Marchand-Forde, R.M., 2009. Postnatal piglet husbandry practices and well-being: the effects of alternative techniques delivered separately. J. Anim. Sci. 87, 1479–1492.

McCafferty, R.E., Pinkstaff, C.A., 1970. A study of sexual dimorphism in Harderian glands of the miniature pig. Anat. Rec. 166, 340.

Mellor, D.J., Diesch, T.J., 2006. Onset of sentience: the potential for suffering in fetal and newborn farm animals. Appl. Anim. Behav. Sci. 100, 48–57.

Mellor, D.J., Gregory, N.G., 2003. Responsiveness, behavioural arousal and awareness in fetal and newborn lambs: experimental, practical and therapeutic implications. N. Zeal. Vet. J. 51, 2–13.

Mellor, D.J., Stafford, K.J., 2004. Animal welfare implications of neonatal mortality and morbidity in farm animals. Vet. J. 168, 118–133.

Mousing, J., Kyrval, J., Jensen, T., Aalbaek, B., Buttenschøn, B., Svensmark, B., Willeberg, P., 1997. Meat safety consequences of implementing visual postmortem meat inspection procedures in Danish slaughter pigs. Vet. Rec. 140, 472–477.

Murata, H., Shimada, N., Yoshioka, M., 2004. Current research on acute phase proteins in veterinary diagnosis: an overview. Vet. J. 168, 28–40.

Napolitano, F., De Rosa, G., Girolami, A., Scavone, M., Braghieri, A., 2011. Avoidance distance in sheep: test–retest reliability and relationship with stockmen attitude. Small Rumin. Res. 99, 81–86.

OIE, 2012. 7th ed. Manual of Diagnostic Tests and Vaccines for Terrestrial Animals, vol. 2. OIE, Paris, France.

Pallarés, F.J., Martínez-Subiela, S., Seva, J., Ramis, G., Fuentes, P., Bernabé, A., Muñoz, A., Cerón, J.J., 2008. Relationship between serum acute phase protein concentrations and lesions in finishing pigs. Vet. J. 177, 369–373.

Penny, R.H.C., Hill, F.W.G., 1973. Abattoir observations of ulceration of the stomach (pars oesophagea) of the pig. Vet. Annu. 14, 55–60.

Pointon, A.M., Davies, P.R., Bahnson, P.B., 1999. Disease surveillance at slaughter. In: Straw, B.E., D'Allaire, S., Mengeling, W.L., Taylor, D.J. (Eds.), Diseases of Swine, eight ed. Blackwell Science, Oxford, UK, p. 1209.

Prunier, A., Mounier, A.M., Hay, M., 2005. Effects of castration, tooth resection, or tail docking on plasma metabolites and stress hormones in young pigs. J. Anim. Sci. 83, 216–222.

Prunier, A., Bonneau, M., von Borell, E.H., Cinotti, S., Gunn, M., Fredriksen, B., Giersing, M., Morton, D.B., Tuyttens, F.A.M., Velarde, A., 2006. A review of the welfare consequences of surgical castration in piglets and the evaluation of non-surgical methods. Anim. Welfare 15, 277–289.

Sanchez-Vazquez, M.J., Strachan, W.D., Armstrong, D., Nielen, M., Gunn, G.J., 2011. The British pig health schemes: integrated systems for large-scale pig abattoir lesion monitoring. Vet. Rec. 169, 413.

Sanchez-Vazquez, M.J., Nielen, M., Edwards, S.A., Gunn, G.J., Lewis, F.I., 2012. Identifying associations between pig pathologies using a multi-dimensional machine learning methodology. BMC Vet. Res. 8, 151.

Scientific Veterinary Committee, 1997. The welfare of intensively kept pigs. Health and Consumer Protection Directorate-General, European Commission. Doc XXIV/B3/ScVC/005/1997. Available from: http://europa.eu.int/comm/food/fs/sc/oldcomm4/out17_en.pdf.

Scott, K., Binnendijk, G.P., Edwards, S.A., Guy, J.H., Kiezebrink, M.C., Vermeer, H.M., 2009. Preliminary evaluation of a prototype welfare monitoring system for sows and piglets (Welfare Quality®) project. Anim. Welfare 18, 441–449.

Spoolder, H., Geudeke, M.J., Van der Peet-Schwering, C.M.C., Soede, N.M., 2009. Group housing of sows in early pregnancy: a review of success and risk factors. Livest. Sci. 125, 1–14.

Stanton, A.L., Widowski, T.M., Kelton, D.F., Leslie, K.E., Leblanc, S.J., Millman, S.T., 2011. Prevalence of sickness behavior in neonatal dairy calves at a commercial heifer facility and associations with ADG and illness. In: Proceedings of the 5th International Conference of the Assessment of Animal Welfare at Farm and Group Level (WAFL), Guelph, Canada. Wageningen Academic Publishers.

Stavrakakis, S., Sandercock, D.A., Watt, F.E., Paterson, E., Hall, S.A., Coe, J.E., Kelly, S., Edwards, S.A., Guy, J.H., 2016. Validation of lameness and joint inflammatory response biomarkers in growing pigs. In: Proceedings of the Universities Federation for Animal Welfare (UFAW) Animal Welfare Conference – Recent Advances in Animal Welfare Science. York, 23 June 2016, p. 94.

Straw, B., Zimmerman, J.J., D'Allaire, S., Taylor, D. (Eds.). 2006. Diseases of Swine. Blackwell Publishing, Iowa.

Swaby, H., Gregory, N.G., 2012. A note on the frequency of gastric ulcers detected during post-mortem examination at a pig abattoir. Meat Sci. 90, 269–271.

Taylor, N.R., Main, D.C.J., Mendl, M., Edwards, S.A., 2010. Tail-biting: a new perspective. Vet. J. 186, 137–147.

Teixeira, D.L., Harley, S., Hanlon, A., O'Connell, N.E., More, S.J., Manzanilla, E.G., Boyle, L.A., 2016. Study on the association between tail lesion score, cold carcass weight, and viscera condemnations in slaughter *pigs*. Front. Vet. Sci. 3, 24.

Telkänranta, H., Marchant-Forde, J.N., Valros, A., 2016. Tear staining in pigs: a potential tool for welfare assessment on commercial farms. Animal 10, 318–325.

Temple, D., Dalmau, A., Ruiz de la Torre, J.L., Manteca, X., Velarde, A., 2011. Application of the Welfare Quality® protocol to assess growing pigs kept under intensive conditions in Spain. J. Vet. Behav. 6, 138–149.

Temple, D., Courboulay, V., Velarde, A., Dalmau, A., Manteca, X., 2012. The welfare of growing pigs in five different production systems in France and Spain: assessment of health. Anim. Welfare 21, 257–271.

Temple, D., Barthélémy, H., Mainau, E., Cozzi, A., Amat, M., Canozzi, M.E., Pageat, P., Manteca, X., 2016. Preliminary findings on the effect of the pig appeasing pheromone in a slow releasing block on the welfare of pigs at weaning. Porcine Health Manag. 2, 3.

Valros, A., 2017. Tail biting. In: Špinka, M. (Ed.), Advances in Pig Welfare. Woodhead Publishing, Duxford, UK.

Van Hirtum, A., Berckmans, D., 2004. Objective recognition of cough sound as a biomarker for aerial pollutants. Indoor Air. 14, 10–15.

Velarde, A., 2007. Skin lesions. In: Geers, R., Velarde, A. (Eds.), On Farm Monitoring of Pig Welfare. Wageningen Academic Publishers, Wageningen, The Netherlands, pp. 79–84.

Velarde, A., Dalmau, A., 2017. Slaughter of pigs. In: Špinka, M. (Ed.), Advances in Pig Welfare. Woodhead Publishing, Duxford, UK.

Waiblinger, S., Knierim, U., Winckler, C., 2001. The development of an epidemiologically based on-farm welfare assessment system for use with dairy cows. Acta Agric. Scand. Sect. A: Anim. Sci. 51, 73–77.

Welfare Quality®, 2009. Welfare Quality® Assessment Protocol for Pigs. Welfare Quality® Consortium, Lelystad, Netherlands.

Whay, H.R., Main, D.C.J., Green, L.E., Webster, A.J.F., 2003. Assessment of the welfare of dairy cattle using animal-based measurements: direct observations and investigation of farm records. Vet. Rec. 153, 197–202.

Whay, H.R., Leeb, C., Main, D.J.C., Green, L.E., Webster, J.F., 2007. Preliminary assessment of finishing pig welfare using animal-based measurements. Anim. Welfare. 16, 209–211.

Wright, A.J., 2012. Animal welfare assessment in veterinary education: its theory and practical application to domestic pigs (*Sus scrofa* domestica). PhD Thesis, University of London, London, UK.

Zonderland, J.J., Wolthuis-Fillerup, M., van Reenen, C.G., Bracke, M.B.M., Kemp, B., den Hartog, L.A., Spoolder, H.A.M., 2003. Prevention and treatment of tail biting in weaned piglets. Appl. Anim. Behav. Sci. 110, 269–281.

Pig–human interactions: Creating a positive perception of humans to ensure pig welfare

13

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13.1 Introduction: importance of good stockmanship

Pig production has largely evolved during the last decades from family units to large industries with huge consequences not only on productivity but also on work organisation. This evolution has been done to the detriment of the time spent with the animals (Grannec, 2010). Moreover, several tasks such as feeding or cleaning almost ceased to be manually-operated and became more and more automated. Stockmen themselves consider they do not have enough time to create a positive or at least neutral relationship with their animals, i.e., a relationship characterised by an absence of fear of humans (Boivin et al., 2012). In that context, we nowadays face the problem of fear of humans in animal production, due to the lack of interactions and time spent with animals. This is even worse in intensive productions compared to (smaller) more extensive productions. Webster (2005) pointed out that in intensive livestock production (pigs but also poultry), welfare problems mainly come from failures of stockmanship, i.e., inadequate care of the animals due to a combination of limited time for individual contact and inadequate attention to the animals' physiological and behavioural needs. Human–animal relationship is thus a major issue in pig production and its sustainability. Research aiming at developing a positive relationship developed from the 1980s, a positive relationship being characterised by a low level of fear and a high level of trust in humans (Waiblinger et al., 2006). This relationship, or rather the way animals react to human beings, is now included in a number of welfare evaluation systems, including the Welfare Quality system (Botreau et al., 2007). Understanding the basis of establishing a positive human–pig relationship through appropriate interactions may have a strong positive impact on pigs, but also on stockpersons.

The objectives of this chapter are to describe the pig–human(s) interactions, their consequences on the human–animal relationship and potential ways of improvement. In the first section we will describe the sensory channels involved in pig–human interactions and relationship. In the second section we will focus on cognitive aspects of the representations pigs may form of humans, i.e., recognition

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and generalisation processes. In the third section we will describe the consequences of the relationship according to its quality, both for pigs and humans. Finally, in the fourth section we will expose some methods to improve the relationship on farms, by using social capacities of pigs and training possibilities of humans.

13.2 Sensory channels in pig–human interactions

Interactions between pigs and humans in the piggeries can occur through a number of sensory channels: acoustic, visual, tactile or chemical. In these interactions, pigs use the same sensory abilities that they use in mutual pig–pig interactions. For instance, when recognising each other, pigs rely first on olfactory (Mendl et al., 2002; Horrell and Hodgson, 1992; Kristensen et al., 2001; Maletinska et al., 2002) and auditory cues (Shillito Walser, 1986; Horrell and Hodgson, 1992; Illmann et al., 2002), and would also use visual cues (McLeman et al., 2008). Similarly, discrimination of humans by pigs is a combination of visual, auditory and/or olfactory cues (Tanida and Nagano, 1998; Koba and Tanida, 2001).

The human voice is the major auditory signal used during daily activities such as feeding or cleaning. The handlers might use their voice with the intention or not of interacting with the pigs. They might speak at a normal level or sometimes sing. However, during more occasional husbandry activities such as transfer of gestating sows to the farrowing crates or preparation and moving fattening pigs for loading into a truck, stockpeople often shout, or produce sounds by whistling, clicking the tongue or clapping their hands (Courboulay et al., 2013) with the aim to make pigs moving faster or prevent them from stopping in the corridors to explore. To have a calm voice would facilitate the development of a positive human–pig relationship (Hulsen and Scheepens, 2007), whereas shouting is alarming for mammals (Waynert et al., 1999). There seem to be personal styles of acoustically interacting with the animals, some people using one way more than the other. Similarly, visual contacts with humans are prominent in commercial stockbreeding units and may occur either when the stockpeople intend to be close to their animals (e.g., feeding, health check, cleaning, moving, farrowing), or for other reasons (e.g., presence for maintenance of equipment). Pigs also use, among other sensory channels, visual cues such as clothing colour or body size when discriminating among people (Koba and Tanida, 1999, 2001). Furthermore, pigs are subjected to human tactile contacts, most of them aversive, throughout their lifespan, but especially at early age. For example, soon after birth, most piglets undergo castration and iron injection. Tail docking and teeth clipping are also still routinely performed in many countries. During these situations, human contact is closely associated with intense physical pain. On the other hand, there are also possibilities for positive physical contacts provided by humans, like stroking and scratching occurring during the human presence in the pen or around feeding. Finally every time a stockperson is present, a potential for interspecific chemical communication is created, even when the human is not physically close to the pigs. Indeed, wild boars, and thus potentially domestic pigs, can smell human odour over hundreds of metres (Spinka, 2009). Olfactory

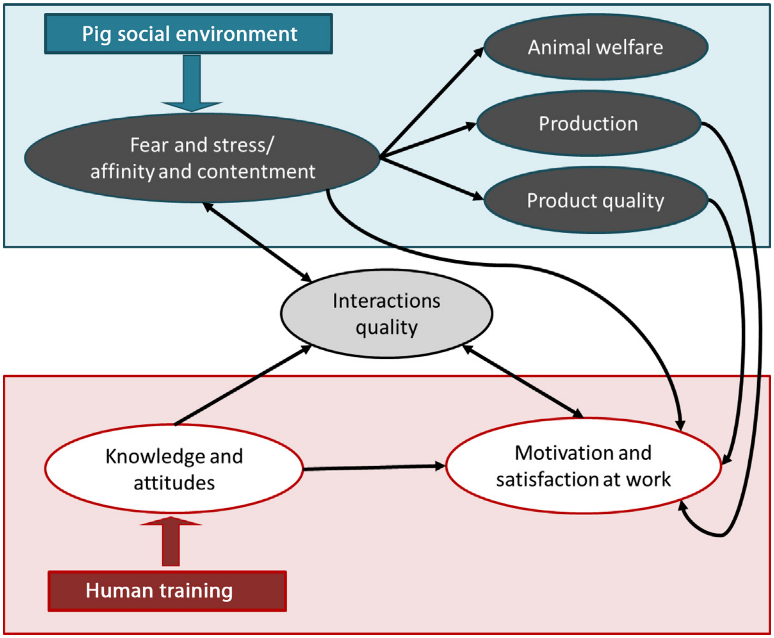

Figure 13.1 Schematic representation of the factors influencing interactions quality in human–pig relationship. In red are the human factors, and in blue the pigs' factors.

awareness is important for the pig (Sommerville and Broom, 1998) although observations show that olfactory cues would not be indispensable for pigs to discriminate between humans (Koba and Tanida, 1999). The different situations of interactions always lead the human to produce sensory signals that are perceived, and probably interpreted, by the pigs. There is also an interindividual variability in how important are the particular sensory channels for each pig (Tanida and Nagano, 1998). All these interactions make pigs create a mental representation of the people. According to the valence of these interactions, they impact human–pig relationship but also pig health and welfare, human work conditions and satisfaction and overall pig productivity (Fig. 13.1).

13.3 Perception of humans by pigs

The behaviour of pigs during interactions with humans depends on pigs' perception of humans, and on the eventual relationship they may have developed with some of them. Perception of humans by pigs can be analysed according to three layers. The first layer would relate to the general experience with humans (e.g., fearfulness, affinity, trust) and refers to the general representation of the human kind by pigs. The second layer would clarify this representation at a deeper level by discriminating between humans as to their roles (e.g., familiar vs unfamiliar humans, or stockpersons vs veterinarians involved in painful procedures). Finally, the third layer would relate to the individual relationship and involve recognition of individual humans and development of differentiated emotional and behavioural responses to them according to the specific previous experience. Behind these three layers of significance of humans for pigs, complex and interacting cognitive processes are involved such as memory, discrimination, recognition and generalisation. The three layers are interconnected.

13.3.1 Representation of humans by pigs

Because humans are, after conspecifics, the second major element of the domestic pigs' social environment, pigs may attribute to them a mental representation. The nature of the memory of humans, either positive or negative, will influence pigs' reactions to humans and thus pigs' welfare (see Section 13.4). The nature of the representation attributed to humans is still poorly understood but current literature gives some cues on how pigs may perceive humans.

On the one hand, it is not uncommon to observe animals exhibiting fear behaviours towards humans (Forkman et al., 2007). Some may argue that humans could be considered as potential predators (Boissy, 1995; Rushen et al., 1999). In sheep, while Kendrick and Baldwin (1987) found that cells in the temporal cortex responded in the same way to faces of humans and sheepdogs, Beausoleil et al. (2005) rather noted that sheep showed higher fear scores to dogs than to humans. Results are conflictual in sheep and it seems that this question has not been addressed in pigs. However, much more work has been done to study the perception of humans as a signal of aversive events. Indeed, humans are often present during stressful and/or painful events (e.g., weaning, castration) and animals may attribute a negative emotional value to humans related to this experience. For example, through a simple conditioning process, pigs can learn to associate humans with electric shocks (Hemsworth et al., 1986a) and they may form a mental representation of humans as predictive of aversive events.

On the other hand, pigs may also develop a conditioned positive representation of humans by associating humans with repeated gentle contacts (Brajon et al., 2015b; Tallet et al., 2014) or food provision (Hemsworth et al., 1996). Tallet et al. (2014) reported that piglets receiving regular stroking and scratching expressed high-pitched vocalisations, which are indicators of stress in pigs (Weary et al., 1999; Tallet et al., 2013), at the experimenter's arrival as to communicate about their frustration of not receiving gentle tactile contact yet. However, piglets (Hemsworth and Barnett, 1992) and adult pigs (Terlouw and Porcher, 2005) actually like making physical contact with humans whether or not they receive tactile contacts, and their motivation to explore humans does not appear to decrease with time (Brajon et al., 2015b), suggesting that the human being has a positive intrinsic value. Some authors proposed that pigs may develop affinity with humans (Tallet et al., 2014). Additionally, Brajon et al. (2015b) suggested that young pigs could perceive humans as entertaining objects or as potential play partners. Indeed, the authors noticed that weaned piglets performed vigorous head movements during their presence, comparable with the 'play marker' of object shaking (Newberry et al., 1988). In pigs, the fact that gentle (e.g., Hemsworth and Barnett, 1992; Tallet et al., 2014) or negative (e.g., Hemsworth and Barnett, 1991; Paterson and Pearce, 1992; Brajon et al., 2015b) contacts participate in decreasing or increasing future fear reactions towards humans shows that pigs develop a memory of humans' behaviour. According to experience, humans may be associated with negative properties and become predictors of negative events (Hemsworth et al., 2011), or they may be associated with positive properties and be considered predictors of positive events (Davis and Taylor, 2001). This memory may last even 5 weeks after experience of human positive or negative contacts (Brajon et al., 2015b).

The question of the mental representation of humans is important, because each representation will be associated with different properties. For instance, if humans are a conditioned stimulus that announces the arrival of a positive reinforcement, pigs will always be looking for the reinforcement at the arrival of the person. Humans will cease to be of interest when they will stop giving the reinforcement, through extinction. Thus the relationship needs to be maintained by predictable actions. However, if an affinity has developed, the mere presence of humans will become a reinforcer, which is easier to maintain at long term.

13.3.2 From discrimination to recognition

General representation gradually develops through each pig's own experience of humans and may allow for rapid identification and even recognition of familiar humans and generalisation to unfamiliar humans. Individual recognition is a prerequisite to true relationship which implies mutual recognition following a series of interactions between two individuals that progressively come to know each other better based on the exchange of interactions (Hinde, 1970).

Discrimination and recognition requires memory and learning capacities. Discrimination is the ability to distinguish two or more elements. Recognition is based on the capacity to discriminate individuals (Mcleman et al., 2005) but also implies individual identification. In contrast, discrimination does not mean that recognition occurs (Gheusi et al., 1994). For instance, one can discriminate familiar from unfamiliar humans without recognising them individually. Studies mainly focused on discrimination capacities which are easier to prove experimentally. Both capacities seem adaptive for domestic pigs. Discrimination of familiar from unfamiliar humans will allow pigs to keep calm or rather try to escape and alert their conspecific according to the person who is present. For example, studies showed that miniature pigs are able to discriminate familiar from unfamiliar humans (Koba and Tanida, 1999, 2001; Tanida and Nagano, 1998). Newly weaned piglets aversively treated by a handler are more fearful towards him than towards a stranger (Sommavilla et al., 2011). On the other hand, following a conditioning involving the delivery of feed rewards from the handler, pigs chose to approach preferentially the familiar handler than a stranger (Tanida and Nagano, 1998).

In contrast to simple discrimination, when familiar handlers differ in their behaviour, animals will learn to recognise them individually. Recognition will thus help pigs to anticipate human behaviour, e.g., the person who gives food is different from the one who just enters to clean the pen. Indeed, weaned piglets can discriminate and recognise a truly gentle handler from a truly rough handler (Brajon et al., 2015b). They prefer to interact with gentle rather than rough handlers (Brajon et al., 2015a; Sommavilla et al., 2011). However, authors are careful to assert that 'recognition' occurs, and rather use the word 'discrimination' (e.g., Sommavilla et al., 2011), as one may wonder if discrimination of two familiar persons means that recognition occurs. The question remains open in pigs, but it seems that horses are able to recognise humans as they do match a voice with the person (Proops and McComb, 2012). Similar kinds of studies are necessary in pigs to confirm that they are really able to recognise humans individually.

13.3.3 Interplay between recognition of individual humans and generalisation of the experience

Discrimination does not always occur even between humans with different behaviours (Hemsworth et al., 1994b) or between familiar and unfamiliar humans (Hemsworth et al., 1996; de Oliveira et al., 2015). As Hemsworth et al. (1994b) hypothesised, pigs can also generalise their experience. The generalisation of the experience does not necessarily mean an inability to discriminate, and both mechanisms may coexist. For instance, after 3 weeks of regular gentle handling, weanling piglets reduce their fear of humans in general, but they still respond differently to familiar and unfamiliar individuals (Tanida et al., 1995). The same was shown in finishing pigs after 40 days of interactions with humans (Terlouw and Porcher, 2005). Pigs generalise their behavioural responses in situations that share some characteristics and appear to require similar reactions, from their point of view, although they may be different in several aspects.

Even if the pigs' experience is mixed and only some humans behave negatively or inconsistently towards them, it may be adaptive to attribute to humans a negative signification ('potentially threatening object') and generalise fear responses to unpredictable humans or strangers. In contrast, it may be beneficial to discriminate gentle humans from potentially threatening humans. The nature of interactions appears to play a preponderant role in recognition and generalisation processes. For instance, in the study of Hemsworth et al. (1994b) two handlers differed in the nature of contact given because one of them gave predominantly negative contact (ratio positive to negative contact: 1:4) and the other gave predominantly positive contact (ratio positive to negative contact: 4:1). Despite this strong quantitative difference, the pigs did not subsequently behave differently towards the two handlers. From the pigs' point of view, both handlers may have been perceived as the same may be because they both used unpredictable negative contact, whatever the ratio, and that negative contacts are more powerful in establishing the type and level of human–animal relationship than positive contacts.

There is a complex interplay between discrimination and generalisation according to a human's behaviour (motionless or approaching) during testing. For example, even if piglets can generalise their positive experience and explore a motionless stranger as they do with a familiar gentle handler, they are more fearful of the stranger when he tries to approach and touch them (Brajon et al., 2015b). Numerous other factors may have an impact on these processes, such as the nature of the environment in which animals are tested (e.g., familiar or unfamiliar, in calves: de Passillé et al., 1996) or the duration of interactions (e.g., in calves: de Passillé et al., 1996).

13.4 Consequences of negative and positive human–pig relationship

There are many situations involving interactions between humans and pigs, and each interaction can impact pig perception of a person or even humans in general. Consequences on pigs can be immediate (fear, stress) but also last for a longer time, affecting pigs and humans health and welfare, as well as productivity (Fig. 13.1).

13.4.1 Consequences on pig health and welfare

13.4.1.1 Fearfulness

Although farm animals have been domesticated for thousands of years, the first reaction of naïve (i.e., animals with no experience of humans) pigs is to be afraid or at least keep a distance of human beings. Exposure to a human being remains one of the potentially most alarming experience for many farm animals (Smulders and Algers, 2009). Humans are the ones who impose contacts onto the animals, and thus it is their responsibility to adapt their behaviour and attitude so that the animals perceive the contact as non-aversive, or even positive. From the very beginning of the animal welfare discussion, the question of the development of fear of humans in farm animals has been highlighted (Brambell, 1965).

In pig production, human presence during the first week is mostly only associated with painful (e.g., castration, tail docking, injections) and stressful (e.g., separation from sow, forced handling) actions. Later in the life of the pig, human beings are associated with further stressful events including weaning, displacements, sanitary (cleaning) and veterinary interventions. Negative interactions are a source of fear for pigs whatever their age. There is a clear link between the number of negative tactile interactions and the level of fear of humans in pigs (Hemsworth and Coleman, 2011), although unpredictable behaviour mixing positive and negative interactions can be as powerful as negative interactions alone (Barnett et al., 1994). Negative interactions lead to an increase of time taken to approach humans and decrease of time spent near humans (review of Pearce et al., 1989; Paterson and

Pearce, 1992; Meunier-Salaün et al., 2007; Hemsworth and Coleman, 2011; Brajon et al., 2015b). They may even lead to chronic stress, measured by high levels of cortisol (Gonyou et al., 1986; Hemsworth and Barnett, 1991).

13.4.1.2 Approach and positive emotions

Many scientific papers show that animals can develop neutral or positive perceptions of human beings if proper actions are taken (e.g., review of Hemsworth, 2007). Repeated gentle contacts induce a decreased fear of humans and even an increased approach towards humans (Paterson and Pearce, 1992; Tanida et al., 1994; Tallet et al., 2014; Brajon et al., 2015b). Approach and contact with a familiar gentle human may lead to positive emotions, as shown in sheep and cattle (Tallet et al., 2005; Schmied et al., 2008). Indicators of positive emotions (e.g., reduced heart rate) have been shown in weaned pigs stroked and scratched for 4 weeks (Tallet et al., 2014), but those preliminary results are still to be confirmed.

13.4.1.3 Health

Because health is the result of many factors including management, housing or hygiene, the impact of negative human interactions, as well as the impact of positive interactions, is difficult to determine. However, indirect evidence exists. A repeated stress impacts negatively the HPA axis (adrenocorticotrophin, cortisol and corticosteroid binding globulin, brain glucocorticoid receptors and corticotropin-releasing hormone) and health markers (lymphocyte proliferation, interleukin-1beta) (Kanitz et al., 2004, 2005). By intensifying the stress level, negative human interactions can modulate negatively pig health. At the opposite, it is suggested that positive emotions induced by positive human interactions may modulate positively the health status (Boissy et al., 2007). In poultry, improved weight gain and feed efficiency has been observed when chickens were handled and spoken to softly (Collins and Siegel, 1987). In this study, the potential stress modulating effect of (positive) human contact was identified as a possible explanation for productivity differences as enhanced disease resistance and immune responses were also found. Similar effects have not been clearly demonstrated in pigs, although levels of glucocorticoids in positively handled pigs are lower compared to negatively handled pigs (handling involving strokes vs electric prod) (Hemsworth et al., 1986a).

13.4.2 Consequences on productivity and product quality

13.4.2.1 Productivity

The effects of the human–animal relationship on pig productivity have been first demonstrated by Hemsworth and his colleagues in the early 1980s (e.g., Hemsworth et al., 1981). A positive human–animal relationship may result in a better growth and a lower level of stillborn piglets (Hemsworth and Coleman, 1998). Evidence on the negative impact of fear of humans on productivity parameters, such as the number of piglets per sow per year, is still growing (Faucitano and Schaefer, 2008).

The stress responses generated by negative human handling may, for example, increase inter-piglet birth intervals and piglet mortality (Janczak et al., 2003; Andersen et al., 2006). Negative handling reduces the pregnancy rate in gilts (Hemsworth et al., 1986a), reduces their attraction to boars in the presence of humans (Pedersen et al., 2003) and can increase the percentage of stillborn piglets (Hemsworth et al., 1999). Furthermore, boars handled unpleasantly were shown to have smaller testicles at a later age and to perform less coordinated mating behaviour than pleasantly handled boars (Hemsworth et al., 1986a). The fear of humans can also indirectly influence the crushing of piglets by the sow in the farrowing crate, as fearful sows tend to change posture (transitions from lie down to stand up) more often when fearful and agitated, leading to potentially more piglets trapped under the sow (Lensink et al., 2009). On the other hand, a positive relationship may also increase the reproductive rate (number of piglets per sow per year: Hemsworth and Coleman, 1998).

13.4.2.2 Meat quality

A positive human–animal relationship on farm may result in a better quality of meat (in veal calves: Lensink et al., 2001a). However, there is little evidence in pigs because most of the experiments failed to show any effect of previous positive handling on meat quality. Counter-examples are studies on the effects of negative handling before slaughtering that have found evident negative effects on carcasses. The presence of a negative handler (refusing contact to approaching pigs) at slaughter tend to accelerate pre-slaughter glycogen breakdown which is associated to meat quality (Terlouw et al., 2005). Rough handling at slaughter tends to increase skin bruise score on the carcass and to induce more exudative meat (Rabaste et al., 2007) than gentle handling. Using an electric prod at loading increases blood lactate and ultimate muscular pH (Correa et al., 2010), resulting in inferior meat quality. Altogether, pigs' fear of humans before slaughter and excessive negative handling pre-slaughter might affect meat quality. More focus on the effects of handlers training at slaughterhouse on the impact of the human–animal relationship on meat quality would be needed.

13.4.3 Consequences for stockpeople

The quality of human–pig relationship has a strong impact on human work with pigs, as it affects pig behaviour and thus the ease of handling. Fear of people is often associated with difficulties to handle animals, because they try to avoid humans and react by baulking (Hemsworth, 2000). On the contrary, positive interactions may facilitate animal handling (English et al., 1999). In turn, job satisfaction of farmers is improved with easier handling.

However, negative interactions may speed up some handling procedures, like loading in a truck (Correa et al., 2010) or emptying a pen (Day et al., 2002).

For instance, the use of an electric prod helps to accelerate loading as it reduces stops and attempts to turn, despite the fact that it increases pig stress (Correa et al., 2010). Therefore, a compromise has probably to be found between using fear inducing actions to make pigs walk in the required direction, and letting pigs walk more slowly but without stress.

13.5 Potential ways of improving the human–pig relationship

The role of the stockperson in the development of a positive human–pig relationship to ensure animal welfare, and human satisfaction at work is crucial (Hemsworth and Coleman, 2011). However, efficient methods need to be developed. These methods should take into account humans and pigs' abilities and sensitivity, as well as working constraints in the piggeries, such as constrained access to animals due to group rearing, and limited available time for human–animal interactions. Here we propose future trends in research to go in this direction, based on new and existing knowledge.

13.5.1 By using pigs' sensitivity to human interactions

A lot of studies were devoted to the consequences of feed provision and gentle tactile contacts on pigs' fear of humans, separately or in combination (e.g., Hemsworth et al., 1996; Pearce et al., 1989). They proved to be efficient methods. However, the methods necessitate spending minutes with each animal every day for a couple of weeks, and therefore have limited practicability in real piggeries. Sending cues or signals through the different sensory channels (visual, auditory, olfactory) may be an alternative way to positively affect the pig perception of humans (Hemsworth and Coleman, 2011), but no methods exist yet. One reason is that we do not know the impact of human odours, voice or visual aspects on the relationship, i.e., fear or attraction to humans. Pigs are highly sensitive to the visual aspect of humans like the posture: they take more time to approach an erected person than a squatted one, and an approaching person than a person not approaching (Hemsworth et al., 1986b). They can also learn to use visual signals to find a hidden feed reward (Nawroth et al., 2013, 2014, 2016). Simple presence may thus be a way to develop a relationship, if appropriate visual cues are used. For instance, simple squatted presence of 5 min for 2 weeks is sufficient to induce human approach in weaned piglets (Brajon et al., 2015b). Acoustic signals may offer a less time-demanding way to increase positive perception of humans, but this has been rarely studied. Farmers themselves tell they use vocal signals (speaking, whistling) when they interact with their animals (Collin et al., 2016). Studies are scarce and not consistent. Recent studies (Bensoussan et al., unpublished data; Tallet et al., 2016) showed that human voice may be used by piglets to adapt their behaviour. However, other experiments failed to show that piglets use vocal information to find a hidden reward (Nawroth and von Borell, 2015; Bensoussan et al., 2016). Furthermore, it seems that pigs make no difference between a loud harsh call and a soft quiet one (Hemsworth et al., 1986b). More investigations are needed to determine if pigs make a difference between different aspects of voices, and if speaking to pigs may help to tame them. Pigs are also probably sensitive to human chemical cues since, for instance, wearing gloves has been shown to decrease human attraction (Hemsworth et al., 1986b). However, there is almost complete paucity of data on this topic and there are still many questions to be solved. For instance, when we put one hand on the back of a pig to make it move forward, do pigs understand our intentions? Is shouting necessary/helpful to make the animals go forward?

13.5.2 By using social capacities

Another aspect that has been poorly investigated to date is the role of the social environment on the development of human–pig relationships (Fig. 13.1). Researchers mostly used individual separated pigs in scientific studies. However, farmers need to forge positive relationships with grouped animals, as pigs are mainly reared and kept in groups. The challenge is to allow farmers, despite the short time they are able to spend with their animals, to be positively perceived by their animals. They could potentially rely on the following aspects.

13.5.2.1 Social facilitation

Social facilitation occurs when the behaviour of an animal is promoted by the simple presence of another individual (Nicol, 1995). Social facilitation in the context of human–pig relationship has never been studied in pigs. On the contrary, veal calves reared alone are more attracted by an unfamiliar person than animals reared in pairs (Lensink et al., 2001b). Thus it is uncertain whether social facilitation could be used to improve human–pig relationships.

13.5.2.2 Social and emotional contagion

The use of conspecifics to develop a positive human–pig relationship might be rather mediated by social contagion, defined as the situation when a behaviour of a companion releases the same behaviour in another individual (Nicol, 1995), or by emotional contagion, when an affective state spreads from one individual to another (Spinka, 2012). Both of these mechanisms exist in pigs (Oostindjer et al., 2014; Düpjan et al., 2011; Goumon and Spinka, 2016). Farmers could take advantage of specific situations such as the farrowing which give them the opportunity to be in contact with the animals, and develop a positive human–animal relationship with a smaller number of them. Then, this relationship could be spread out within the group or litter, through behavioural and/or emotional contagion. The difficulty here resides in the fact that all the animals do not have the same reactivity to humans, or the same position within the group, and thus establishing a positive relationship through one animal may necessitate to be based on the social rules of the group.

Social contagion of human–animal relationship seems to work in horses. Giving positive contact to the dam makes the foal interact more easily with humans, even if individual variability remains high (Henry et al., 2007). A recent experiment (de Oliveira et al., 2015) showed that in several aspects of a human approach test (e.g., vocalisation, staying in the perimeter zone), the non-handled and handled piglets from the same litter behaved similarly and differed from both the all-handled and non-handled litters, suggesting that within-litter contagion of the experience with humans had occurred. Further research in this direction is thus needed.

13.5.3 By using human capacities to train and modify their attitude

Knowing that human behaviour toward pigs depends on their attitude (Fig. 13.1), several training methods were developed, like ProHand Pigs in Australia or Quality Handling in Europe (Welfare Quality project). Quality handling is a computerised program aiming at training pig farmers to understand the impact of a positive human–pig relationship, and to modify their attitude and beliefs. Both programs also include group discussions and access to guidelines and posters. Several studies showed that training is efficient at modifying farmers' behaviour and thus productivity of the farms. For instance, training may decrease negative behaviours and increase belief in positive ones (petting) (Hemsworth et al., 1994a; Coleman et al., 2000). As a consequence, it also decreases the fear responses of pigs toward humans (Hemsworth et al., 1994a; Coleman et al., 2000). One problem of this kind of programs is that its effects may be mostly limited to people already sensitive to human–pig relationship, and thus the positive effects would highly depend on people's motivation. Also, it may have a cost that is difficult to accept for farmers. We still miss data on the balance between costs and benefits of such methods. Spreading these methods more widely in the farming community would probably necessitate to include them into the curricula of the farmers' training and engage the teachers.

13.6 Conclusion

Pigs and humans share a lot of their sensorial capacities that ensure that a large variety of interactions is possible, thus defining a large range of possible relationships. The cognitive capacities of pigs enable them to discriminate between humans and to recognise them individually, but also to generalise their reactions to other humans when necessary. Even if the pig husbandry systems develop to higher degrees of automation, there should still be a place for every day human–pig interactions. This is important because these interactions may impact a lot animal welfare, production and human work. However, knowledge on methods that farmers may use to maintain a positive relationship with their animals is still lacking, probably because it is a difficult to develop short lasting, cheap and efficient methods.

For the future, we propose that farmers should be trained to know the sensory and social capacities of their animals and to develop positive attitudes toward them. Such training will enable the humans to engage the pigs with the appropriate human-borne cues and signals and to influence their groups through tailored social interactions. The key to harmonious human–pig relationships may reside in informed, knowledge-based care of everyday human–pig interaction.

References

Andersen, I.L., Berg, S., Boe, K.E., Edwards, S., 2006. Positive handling in late pregnancy and the consequences for maternal behaviour and production in sows. Appl. Anim. Behav. Sci. 99, 64–76.

Barnett, J.L., Hemsworth, P.H., Hennessy, D.P., Mccallum, T.H., Newman, E.A., 1994. The effects of modifying the amount of human contact on behavioural, physiological and production responses of laying hens. Appl. Anim. Behav. Sci. 41, 87–100.

Beausoleil, N.J., Stafford, K.J., Mellor, D.J., 2005. Sheep show more aversion to a dog than to a human in an arena test. Appl. Anim. Behav. Sci. 91, 219–232.

Bensoussan, S., Cornil, M., Meunier-Salaün, M.-C., Tallet, C., 2016. Piglets learn to use combined human-given visual and auditory signals to find a hidden reward in an object choice task. PLoS One 11, e0164988.

Boissy, A., 1995. Fear and fearfulness in animals. Quarter. Rev. Biol. 70, 165–191.

Boissy, A., Manteuffel, G., Jensen, M.B., Moe, R.O., Spruijt, B., Keeling, L.J., Winckler, J., Forkman, B., Dimitrov, I., Langbein, J., Bakken, M., Veissier, I., Aubert, A., 2007. Assessment of positive emotions in animals to improve their welfare. Physiol. Behav. 92, 375–397.

Boivin, X., Bensoussan, S., L'hotellier, N., Bignon, L., Brives, H., Brule, A., Godet, J., Grannec, M.L., Hausberger, M., Kling-Eveillard, F., Tallet, C., Courboulay, V., 2012. Humans and livestock animals at work: toward a multidisciplinary approach of relational practices. Inra Prod. Anim. 25, 159–168.

Botreau, R., Bonde, M., Butterworth, A., Perny, P., Bracke, M.B.M., Capdeville, J., Veissier, I, 2007. Aggregation of measures to produce an overall assessment of animal welfare. Part 1: a review of existing methods. Animal 1, 1179–1187.

Brajon, S., Laforest, J.-P., Bergeron, R., Tallet, C., Devillers, N., 2015a. The perception of humans by piglets: recognition of familiar handlers and generalisation to unfamiliar humans. Anim. Cogn. 18, 1299–1316.

Brajon, S., Laforest, J.-P., Bergeron, R., Tallet, C., Hötzel, M.-J., Devillers, N., 2015b. Persistency of the piglet's reactivity to the handler following a previous positive or negative experience. Appl. Anim. Behav. Sci. 162, 9–19.

Brambell, F.W.R., 1965. Report of the technical committee to enquire into welfare of animals kept under intensive livestock husbandry systems. Her Majesty Stationery Office, pp. 1–84.

Coleman, G.J., Hemsworth, P.H., Hay, M., Cox, M., 2000. Modifying stockperson attitudes and behaviour towards pigs at a large commercial farm. Appl. Anim. Behav. Sci. 66, 11–20.

Collin, S., Bensoussan, S., Courboulay, V., Kling-Eveillard, F., Meunier-Salaün, M.C., Tallet, C., 2016. Survey on communication practices of pig farmers with their animals. In: IFIP, I. (Ed.), 48th Days of Swine Research, Paris.

Collins, J., Siegel, P., 1987. Human handling, flock size and responses to an *E. coli* challenge in young chickens. Appl. Anim. Behav. Sci. 19, 183−188.

Correa, J.A., Torrey, S., Devillers, N., Laforest, J.P., Gonyou, H.W., Faucitano, L., 2010. Effects of different moving devices at loading on stress response and meat quality in pigs. J. Anim. Sci. 88, 4086−4093.

Courboulay, V., Tallet, C., Bensoussan, S., 2013. Development and use of a tool for describing human practices and pig responses during handling. In: IFIP, I. (Ed.), Journées de la Recherche Porcine, Paris, pp. 73−74.

Davis, H., Taylor, A., 2001. Discrimination between individual humans by domestic fowl (Gallus gallus domesticus). Br. Poult. Sci. 42, 276−279.

Day, J.E.L., Spoolder, H.A.M., Burfoot, A., Chamberlain, H.L., Edwards, S.A., 2002. The separate and interactive effects of handling and environmental enrichment on the behaviour and welfare of growing pigs. Appl. Anim. Behav. Sci. 75, 177−192.

De Oliveira, D., Paranhos Da Costa, M.J.R., Zupan, M., Rehn, T., Keeling, L.J., 2015. Early human handling in non-weaned piglets: effects on behaviour and body weight. Appl. Anim. Behav. Sci. 164, 56−63.

De Passillé, A.M., Rushen, J., Ladewig, J., Petherick, C., 1996. Dairy calves' discrimination of people based on previous handling. J. Anim. Sci. 74, 969−974.

Düpjan, S., Tuchscherer, A., Langbein, J., Schon, P.C., Manteuffel, G., Puppe, B., 2011. Behavioural and cardiac responses towards conspecific distress calls in domestic pigs (*Sus scrofa*). Physiol. Behav. 103, 445−452.

English, P.R., Grant, S.A., Mcpherson, O., Edwards, S.A., 1999. Evaluation of the effects of the positive 'befriending' of sows and gilts ('pleasant' treatment) prior to parturition and in early lactation on sow behaviour, the process of parturition and piglet survival. In: Russel, A.J.F., Morgan, C.A., Savory, C.J., Appleby, M.C., Lawrence, T.L.J. (Eds.), Farm Animal Welfare – Who Writes the Rules? Proceedings of An International Symposium Organized by The British Society of Animal Science, Edinburgh, UK, 1999. British Society of Animal Science, Occasional Publication.

Faucitano, L., Schaefer, A.L., 2008. Welfare of pigs from birth to slaughter, Versailles (FRA), Editions QUAE.

Forkman, B., Boissy, A., Meunier-Salaun, M.C., Canali, E., Jones, R.B., 2007. A critical review of fear tests used on cattle, pigs, sheep, poultry and horses. Physiol. Behav. 92, 340−374.

Gheusi, G., Bluth, R.M., Goodall, G., Dantzer, 1994. Social and individual recognition in rodents: methodological aspects and neurobiological bases. Behav. Process. 33, 59−88.

Gonyou, H.W., Hemsworth, P.H., Barnett, J.L., 1986. Effects of frequent interactions with humans on growing pigs. Appl. Anim. Behav. Sci. 16, 269−278.

Goumon, S., Spinka, M., 2016. Emotional contagion of distress in young pigs is potentiated by previous exposure to the same stressor. Anim. Cogn. 19, 501−511.

Grannec, M.L., 2010. Temps de travail: évaluer le temps disponible pour l'éleveur. Atout Porc. Bretagne, juillet 20–23.

Hemsworth, P., 2000. Behavioural principles of pig handling. In: Grandin, T. (Ed.), Livestock Handling and Transport, 2nd Ed. CAB International, Oxfordshire, UK.

Hemsworth, P.H., 2007. Ethical stockmanship. Aust. Vet. J. 85, 194−200.

Hemsworth, P.H., Barnett, J.L., 1991. The effects of aversively handling pigs, either individually or in groups, on their behaviour, growth and corticosteroids. Appl. Anim. Behav. Sci. 30, 61−72.

Hemsworth, P.H., Barnett, J.L., 1992. The effects of early contact with humans on the subsequent level of fear of human in pigs. Appl. Anim. Behav. Sci. 35, 83−90.

Hemsworth, P.H., Coleman, G.J., 1998. Chapter 3: Human–animal interactions and animal productivity and welfare. In: Hemsworth, P.H., Coleman, G.J. (Eds.), Human–Livestock Interactions: The Stockperson and the Productivity and Welfare of Intensively Farm Animals. CAB international, Bristol, UK.

Hemsworth, P.H., Coleman, G.J., 2011. Human–Livestock Interactions, second ed. CAB international, Chippenham, UK.

Hemsworth, P.H., Brand, A., Willems, P., 1981. The behavioural response of sows to the presence of human beings and its relation to productivity. Livest. Prod. Sci. 8, 67–74.

Hemsworth, P.H., Barnett, J.L., Hansen, C., 1986a. The influence of handling by humans on the behaviour, reproduction and corticosteroids of male and female pigs. Appl. Anim. Behav. Sci. 15, 303–314.

Hemsworth, P.H., Gonyou, H.W., Dziuk, P.J., 1986b. Human communication with pigs: the behavioural response of pigs to specific human signals. Appl. Anim. Behav. Sci. 15, 45–54.

Hemsworth, P.H., Coleman, G.J., Barnett, J.L., 1994a. Improving the attitude and behavior of stockpersons towards pigs and the consequences on the behavior and reproductive-performance of commercial pigs. Appl. Anim. Behav. Sci. 39, 349–362.

Hemsworth, P.H., Coleman, G.J., Cox, M., Barnett, J.L., 1994b. Stimulus generalization: the inability of pigs to discriminate between humans on the basis of their previous handling experience. Appl. Anim. Behav. Sci. 40, 129–142.

Hemsworth, P.H., Verge, J., Coleman, G.J., 1996. Conditioned approach-avoidance responses to humans: the ability of pigs to associate feeding and aversive social experiences in the presence of humans with humans. Appl. Anim. Behav. Sci. 50, 71–82.

Hemsworth, P.H., Pedersen, V., Cox, M., Cronin, G.M., Coleman, G.J., 1999. A note on the relationship between the behavioural response of lactating sows to humans and the survival of their piglets. Appl. Anim. Behav. Sci. 65, 43–52.

Hemsworth, P.H., Rice, M., Karlen, M.G., Calleja, L., Barnett, J.L., Nash, J., Coleman, G.J., 2011. Human–animal interactions at abattoirs: relationships between handling and animal stress in sheep and cattle. Appl. Anim. Behav. Sci. 135, 24–33.

Henry, S., Briefer, S., Richard-Yris, M.A., Hausberger, M., 2007. Are 6-month-old foals sensitive to dam's influence? Dev. Psychobiol. 49, 514–521.

Hinde, R.A., 1970. Animal Behaviour. 2nd edition McGraw-Hill, New York.

Horrell, I., Hodgson, J., 1992. The bases of sow-piglet identification. 2. Cues used by piglets to identify their dam and home pen. Appl. Anim. Behav. Sci. 33, 329–343.

Hulsen, J., Scheepens, K., 2007. Signes de porcs – observer, réfléchir, agir. Roodbont editions.

Illmann, G., Schrader, L., Špinka, M., Šustr, P., 2002. Acoustical mother-offspring recognition in pigs (*Sus scrofa domestica*). Behaviour 139, 487–505.

Janczak, A.M., Pedersen, L.J., Rydhmer, L., Bakken, M., 2003. Relation between early fear- and anxiety-related behaviour and maternal ability in sows. Appl. Anim. Behav. Sci. 82, 121–135.

Kanitz, E., Tuchscherer, M., Puppe, B., Tuchscherer, A., Stabenow, B., 2004. Consequences of repeated early isolation in domestic piglets (Sus scrofa) on their behavioural, neuroendocrine, and immunological responses. Brain Behav. Immun. 18, 35–45.

Kanitz, E., Otten, W., Tuchscherer, M., 2005. Centrel and peripheral effects of repeated noise stress on hypothalamic-pituitary-adrenocortical axis in pigs. Livest. Prod. Sci. 94, 213–224.

Kendrick, K.M., Baldwin, B.A., 1987. Cells in temporal cortex of conscious sheep can respond preferentially to the sight of faces. Science 236, 448–450.

Koba, Y., Tanida, H., 1999. How do miniature pigs discriminate between people? The effect of exchanging cues between a non-handler and their familiar handler on discrimination. Appl. Anim. Behav. Sci. 61, 239–252.
Koba, Y., Tanida, H., 2001. How do miniature pigs discriminate between people?: discrimination between people wearing coveralls of the same colour. Appl. Anim. Behav. Sci. 73, 45–58.
Kristensen, H.H., Jones, R.B., Schofield, C., White, R.P., Wathes, C.M., 2001. The use of olfactory and other cues for social recognition by juvenile pigs. Appl. Anim. Behav. Sci. 72, 321–333.
Lensink, B.J., Fernandez, X., Cozzi, G., Florand, L., Veissier, I., 2001a. The influence of farmers' behavior on calves' reactions to transport and quality of veal meat. J. Anim. Sci. 79, 642–652.
Lensink, B.J., Raussi, S., Boivin, X., Pyykkonen, M., Veissier, I., 2001b. Reactions of calves to handling depend on housing condition and previous experience with humans. Appl. Anim. Behav. Sci. 70, 187–199.
Lensink, B.J., Leruste, H., Bretagne, T.D., Bizeray-Filoche, D., 2009. Sow behaviour towards humans during standard management procedures and their relationship to piglet survival. Appl. Anim. Behav. Sci. 119, 151–157.
Maletinska, J., Spinka, M., Vichova, J., Stehulova, I., 2002. Individual recognition of piglets by sows in the early post-partum period. Behaviour 139, 975–991.
Mcleman, M.A., Mendl, M., Jones, R.B., White, R., Wathes, C.M., 2005. Discrimination of conspecifics by juvenile domestic pigs, *Sus scrofa*. Anim. Behav. 70, 451–461.
Mcleman, M.A., Mendl, M.T., Jones, R.B., Wathes, C.M., 2008. Social discrimination of familiar conspecifics by juvenile pigs, *Sus scrofa*: development of a non-invasive method to study the transmission of unimodal and bimodal cues between live stimuli. Appl. Anim. Behav. Sci. 115, 123–137.
Mendl, M., Randle, K., Pope, S., 2002. Young female pigs can discriminate individual differences in odours from conspecific urine. Anim. Behav. 64, 97–101.
Meunier-Salaün, M.-C., Courboulay, V., Scott, K., Guy, J.H., Edwards, S., 2007. Mesure de la relation Homme-Animal chez le porc en croissance: validation d'un test applicable en élevage. In: EDS, I. (Ed.), Journées de la Recherche Porcine, Paris, pp. 85–86.
Nawroth, C., Von Borell, E., 2015. Domestic pigs' (*Sus scrofa* domestica) use of direct and indirect visual and auditory cues in an object choice task. Anim. Cogn. 18, 757–766.
Nawroth, C., Ebersbach, M., Von Borell, E., 2013. Are juvenile domestic pigs (*Sus scrota* domestica) sensitive to the attentive states of humans?—the impact of impulsivity on choice behaviour. Behav. Process. 96, 53–58.
Nawroth, C., Ebersbach, M., Von Borell, E., 2014. Juvenile domestic pigs (*Sus scrofa* domestica) use human-given cues in an object choice task. Anim. Cogn. 17, 701–713.
Nawroth, C., Ebersbach, M., Von Borell, E., 2016. Are domestic pigs (*Sus scrofa* domestica) able to use complex human-given cues to find a hidden reward? Anim. Welfare 25, 185–190.
Newberry, R.C., Woodgush, D.G.M., Hall, J.W., 1988. Playful behavior of piglets. Behav. Process. 17, 205–216.
Nicol, C.J., 1995. The social transmission of information and behaviour. Appl. Anim. Behav. Sci. 44, 79–98.
Oostindjer, M., Kemp, B., Van Den Brand, H., Bolhuis, J.E., 2014. Facilitating 'learning from mom how to eat like a pig' to improve welfare of piglets around weaning. Appl. Anim. Behav. Sci. 160, 19–30.

Paterson, A.M., Pearce, G.P., 1992. Growth, response to humans and corticosteroids in male pigs housed individually and subjected to pleasant, unpleasant or minimal handling during rearing. Appl. Anim. Behav. Sci. 34, 315–328.

Pearce, G.P., Paterson, A.M., Pearce, A.N., 1989. The influence of pleasant and unpleasant handling and the provision of toys on the growth and behaviour of male pigs. Appl. Anim. Behav. Sci. 23, 27–37.

Pedersen, L.J., Damm, B.I., Kongsted, A.G., 2003. The influence of adverse or gentle handling procedures on sexual behaviour in fearful and confident sows. Appl. Anim. Behav. Sci. 83, 277–290.

Proops, L., Mccomb, K., 2012. Cross-modal individual recognition in domestic horses (*Equus caballus*) extends to familiar humans. Proc. R. Soc. B: Biol. Sci. 279, 3131–3138.

Rabaste, C., Faucitano, L., Saucier, L., Mormede, P., Correa, J.A., Giguere, A., Bergeron, R., 2007. The effects of handling and group size on welfare of pigs in lairage and their influence on stomach weight, carcass microbial contamination and meat quality. Can. J. Anim. Sci. 87, 3–12.

Rushen, J., Taylor, A.A., De Passill, A.M., 1999. Domestic animals' fear of humans and its effect on their welfare. Appl. Anim. Behav. Sci. 65, 285–303.

Schmied, C., Waiblinger, S., Scharl, T., Leisch, F., Boivin, X., 2008. Stroking of different body regions by a human: effects on behaviour and heart rate of dairy cows. Appl. Anim. Behav. Sci. 109, 25–38.

Shillito Walser, E.E., 1986. Recognition of the sow's voice by neonatal piglets. Behaviour 99, 177–188.

Smulders, F.J.M., Algers, B., 2009. Welfare of Production Animals: Assessment and Management of Risks. Wageningen Academic Publisher, Wageningen, The Netherlands.

Sommavilla, R., Hoetzel, M.J., Dalla Costa, O.A., 2011. Piglets' weaning behavioural response is influenced by quality of human-animal interactions during suckling. Animal 5, 1426–1431.

Sommerville, B., Broom, D., 1998. Olfactory awareness. Appl. Anim. Behav. Sci. 57, 269–286.

Spinka, M., 2009. Behaviour of pigs. In: Jensen, P. (Ed.), The Ethology of Domestic Animals, 2nd Edition—An Introductory Text. CAB International, UK.

Spinka, M., 2012. Social dimension of emotions and its implication for animal welfare. Appl. Anim. Behav. Sci. 138, 170–181.

Tallet, C., Veissier, I., Boivin, X., 2005. Human contact and feeding as rewards for the lamb's affinity to their stockperson. Appl. Anim. Behav. Sci. 94, 59–73.

Tallet, C., Linhart, P., Policht, R., Hammerschmidt, K., Simecek, P., Kratinova, P., Spinka, M., 2013. Encoding of situations in the vocal repertoire of piglets (*Sus scrofa*): a comparison of discrete and graded classifications. PLoS One 8, e7184.

Tallet, C., Sy, K., Prunier, A., Nowak, R., Boissy, A., Boivin, X., 2014. Behavioural and physiological reactions of piglets to gentle tactile interactions vary according to their previous experience with humans. Livest. Sci. 167, 331–341.

Tallet, C., Rakotomanhandry, M., Guerin, C., Lemasson, A., Hausberger, M., 2016. Postnatal auditory preferences in piglets differ according to mother's emotional experience with the sounds during gestation. Sci. Rep., Available from: http://dx.doi.org/10.1038/srep37238.

Tanida, H., Nagano, Y., 1998. The ability of miniature pigs to discriminate between a stranger and their familiar handler. Appl. Anim. Behav. Sci. 56, 149–159.

Tanida, H., Miura, A., Tanaka, T., Yoshimoto, T., 1994. The role of handling in communication between humans and weanling pigs. Appl. Anim. Behav. Sci. 40, 219–228.

Tanida, H., Miura, A., Tanaka, T., Yoshimoto, T., 1995. Behavioural responses to humans in individually handled weanling pigs. Appl. Anim. Behav. Sci. 42, 249–259.

Terlouw, E.M.C., Porcher, J., 2005. Repeated handling of pigs during rearing. I. Refusal of contact by the handler and reactivity to familiar and unfamiliar humans. J. Anim. Sci. 83, 1653–1663.

Terlouw, E.M.C., Porcher, J., Fernandez, X., 2005. Repeated handling of pigs during rearing. I. Effect of reactivity to humans on aggression during mixing and on meat quality. J. Anim. Sci. 83, 1664–1672.

Waiblinger, S., Boivin, X., Pedersen, V., Tosi, M.-V., Janczak, A.M., Visser, E.K., Jones, R. B., 2006. Assessing the human–animal relationship in farmed species: a critical review. Appl. Anim. Behav. Sci. 101, 185–242.

Waynert, D.F., Stookey, J.M., Schwartzkopf-Genswein, K.S., Watts, J.M., Waltz, C.S., 1999. The response of beef cattle to noise during handling. Appl. Anim. Behav. Sci. 62, 27–42.

Weary, D.M., Appleby, M.C., Fraser, D., 1999. Responses of piglets to early separation from the sow. Appl. Anim. Behav. Sci. 63, 289–300.

Webster, J., 2005. Animal Welfare, Limping Towards Eden. Blackwell Publishing Ltd, Oxford, UK.

Positive welfare: What does it add to the debate over pig welfare?

15

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15.1 Introduction

Pigs have always been a key species in debates over farm animal welfare. Pigs featured in a book entitled *Animal Machines* (Harrison, 1964) that gave a lay account of the farm animal welfare issues that emerged in the second half of the 20th century. Pigs were given their own section in 'The Brambell Report' (Brambell, 1965) which followed as a response to the public concern raised by Harrison's book in the United Kingdom. Brambell (1965) objected to a number of features of intensive pig production including the use of fully slatted floors, high stocking densities, poor air quality, tail-biting and use of tail docking and close confinement of sows. As is apparent from this and other chapters in this book, many of these concerns remain current today.

It is arguable that of all farmed species, pigs have been amongst the most adversely affected in terms of their welfare as a result of the process of intensification. We know that much of the 'wild-type' or 'natural' behaviour of the species remains despite the process of domestication (e.g., Stolba and Wood-Gush, 1989). We are also gaining increased understanding of the cognitive and emotional capacities of pigs (e.g., Held et al., 2001; Reimert et al., 2013; Goumon and Špinka, 2015), and increasingly accept that pigs are a good model for studies of human brain and behaviour (Lind et al., 2007). Yet at the same time, modern pig production systems remain often highly constraining with respect to pigs' behavioural and psychological capacities. Furthermore, the likelihood is that there will be continuing pressure for further intensification of pig production. For example, there is no indication of a slowing down in the rate of the 'technical development' of pig production to improve on production targets (e.g., see Baxter et al., 2013; Rutherford et al., 2013; Ocepek et al., 2017; Baxter et al., 2017 Chapter 2: Sow welfare in the farrowing crate and alternatives; Baxter and Edwards, 2017 Chapter 3; Piglet mortality and morbidity: inevitable or unacceptable?, for analysis of the welfare implications of current and future selection pressure for larger litters). There is also wider pressure for agriculture to intensify, albeit 'sustainably', given the combination of land-use constraints

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and concerns over environmental degradation, climate change and food security (e.g., Garnett et al., 2013). Finally the pressure on pig prices seems set to continue for the foreseeable future (e.g., OECD and FAO, 2016) that limits the opportunity for profits from pig production to be invested in development of production systems including those that better meet the animals' requirements.

The trend for increasing intensification of pig production with concomitant and long-standing concerns over pig welfare is part of the backdrop to this chapter. However our main aim is to address the development of what we refer to as 'positive welfare'. We describe the development of this relatively recent concept, and its implications for pig welfare including what positive welfare may add to the debate over pig welfare in intensive production systems. We also identify parallel and potentially influential developments in understanding positive aspects of quality of life (henceforth QoL) in the life sciences more generally.

15.2 Origins of 'positive animal welfare'

There are antecedents of the 'positive animal welfare' concept to be found in the work of 18th and 19th century moral philosophers such as Mill and Bentham (e.g., Acton, 1961), and more recently from the early days of modern animal welfare science (e.g., Fraser and Duncan, 1998). Scientific interest in 'positive welfare' has gained momentum with writings such as Bracke and Hopster (2006), Yeates and Main (2008) and Mellor (2016a). Following these scientific papers, the UK Farm Animal Welfare Council (FAWC) wrote an influential report on the future of farm animal welfare (FAWC, 2009). In that report FAWC developed a framework for improving the QoL of farmed livestock and although the report did not refer to positive welfare specifically it was clearly influenced by the developing scientific interest in positive welfare. The inclusion of positive animal-based welfare measures such as the ability to move freely and a positive human–animal relationship among the proposed guiding principles for OIE animal welfare standards (World Organisation for Animal Health (OIE), 2016), reflects that positive welfare is now an active topic of discussion on the world stage.

In addressing why the animal welfare science community began writing about positive welfare we have considered the assumptions or premises that underpin interest in the concept. The following premises seem to underlie the development of the positive welfare concept:

Premise 1: Since the start of the modern animal welfare debate (post 1960s) the focus has been mainly on negative aspects of welfare.

There are clear statements relating to this premise in the following:

> *The vast majority of concern for animal welfare appears to be centred upon negative concepts.*
>
> *Yeates and Main (2008).*

> *Animal welfare is usually considered primarily in terms of the animal's negative experiences.*
>
> Phillips (2008).

Furthermore the Five Freedoms, often regarded as the most influential framework for animal welfare, have been increasingly seen to be wanting with respect to positive welfare including by FAWC itself:

> *One criticism of the Five Freedoms is their focus on poor welfare and suffering. This focus was undoubtedly appropriate at the time they were devised but the requirement to provide for an animal's needs in the new Animal Welfare Acts implies that good welfare should be an ambition too.*
>
> FAWC (2009).

> *Notwithstanding its widely beneficial influence, the Five Freedoms paradigm has. . .sought to focus attention on the negative experiences and states that were understood to contribute to welfare problems of serious concern at the time.*
>
> Mellor (2016a).

> *The 5 Freedoms have essentially become the global animal welfare framework since they were first derived by FAWC. . .The concern lies in 4 of the freedoms essentially being about prevention of harms (Freedom from: hunger and thirst; discomfort; pain, injury and disease; fear and stress) with only the . . .Freedom To Express Normal Behaviour perhaps providing more of a positive note, although without explicitly valuing positive experience.*
>
> Yeates and Main (2008).

It is worth noting that, despite the supposed deficiencies of the Five Freedoms, Webster (2016) praises the Five Freedoms as simple signposts to right action. McCulloch (2013) makes a case for the Five Freedoms being an impactful approach to improving animal welfare, by providing aspirational ideas on how animals could live good lives through preventing negatives but also (implicitly) promoting positives particularly through expression of normal behaviour.

As others have pointed out, a focus on the negatives has also been the case in other areas of life sciences including the study of human psychology (e.g., Myers and Diener, 2012, and also in nonhuman primate research, King and Landau, 2003).

> *The nonhuman primate psychological well-being literature thus has similarities to human clinical and personality literature that during the earlier part of this century emphasised negative emotions, depression, anxiety and other multiple manifestations of misery and maladaptability far more than the positive emotions of joy and happiness. A recent review Myers and Diener (2012) noted that human literature on negative states exceeded that on positive states by a ratio of 17 to 1.*
>
> King and Landau (2003).

In order to investigate whether a similar focus on negatives dominates current pig welfare research, we carried out a search of key words with the search term

Figure 15.1 A word cloud produced from a literature search of pig welfare papers (using Web of Science and the search term 'pig welfare'). Papers were taken from the last 5 years and the words that best described the aims of the paper (taken from the title, abstract and key words) were compiled and put through a word cloud generator (http://www.wordclouds.com/).

'pig welfare' using Web of Science. We took papers from the last 5 years (2011–16) and extracted those key words from the title, abstract and key words that best illustrated the main aims of the paper (see Fig. 15.1).

The evidence from this semi-quantitative approach would indeed support Premise 1 with respect to pig welfare research. There are positive aspects here, in particular implied by the key word 'enrichment', but similar to the situation in human psychology the weighting is clearly on the negative side. It is also interesting, and somewhat surprising, how many of the papers were targeted at the end of the pigs' life, approaching this from a 'human utility' perspective with a focus on 'meat quality'.

Premise 2: There is increasing scientific acceptance of animals having the capacity for experiencing positive emotions (or affects):

The following statements illustrate this premise:

> *It is now widely accepted that good welfare is not simply the absence of negative experiences, but rather is primarily the presence of positive experiences such as pleasure.*
>
> *Boissy et al. (2007).*

An abundance of neuroscience evidence indicates that ... the experiential states of happiness and sadness, as well as the other basic affective states are strongly dependent on sub-neocortical limbic circuitries that we share with the other mammals.
Burgdorf and Panksepp (2006).

Emotional experiences are valenced—they are perceived as positive or negative, rewarding or punishing, pleasant or unpleasant—neutral states are not emotional states.
Mendl et al. (2010).

In this review, therefore, some attention is given to negative affects and their relationships to poor animal welfare, but the primary focus is the positive affects animals may experience when they successfully engage in rewarding goal-directed behaviours, encapsulated in the concept of positive affective engagement.
Mellor (2015a).

The wider acceptance of positive emotions in animals is supported by research in a range of disciplines including neuroscience and the behavioural sciences (see Boissy et al., 2007; Burgdorf and Panksepp, 2006; Mellor, 2015a, for reviews). However, detailed analysis of the assumption that animals are capable of experiencing sensations and emotions in some way analogous to humans does reveal the complexity of interpreting the underlying evidence (e.g., Mendl and Paul, 2004; Dawkins, 2017). This is not surprising as establishing evidence for the biological basis of animal sentience seems essentially as difficult as establishing the biology of human consciousness (e.g., Chalmers, 2007). Nonetheless despite the philosophical challenges and complexity of the science, the concept of animal sentience has become enshrined in law both in the EU (e.g., Bennett and Blaney, 2002) and also some individual countries including, for instance the United Kingdom and the Czech Republic. The recent trend within the scientific community towards acceptance of positive emotions in animals as a topic worthy of research may therefore be seen as a continuation of the development of animal welfare concerns and the acceptance of animal sentience that has emerged since the 1960s (e.g., Woods, 2012).

Moreover, there has been significant progress in recent decades in our understanding of the origins of affective states and their relevance to welfare. Two main types of valenced affective states have been distinguished. The first category consists of homeostasis-related affects (Denton et al., 2009) such as pain (Herskin and Di Giminiani, 2017 Chapter 11: Pain in pigs: Characterisation, mechanisms and indicators), thirst (Denton et al., 1999) and hunger (D'Eath et al., 2017 Chapter 7: Mitigating hunger in pregnant sows). The second class comprises 'emotional affects' arising from the limbic system (Panksepp, 2011) including fear (Boissy, 1995), curiosity/seeking (Špinka and Wemelsfelder, 2011), anger/rage/frustration (Panksepp and Zellner, 2004), sexual attraction, parental nurturance and playful fun (Špinka et al., 2001). Both classes of affective states involve subcortical processes and may be modified or regulated by the cortex, although neuroscientists disagree whether subcortical activity alone is sufficient to generate affective experiential states (Denton et al., 2009; Panksepp et al., 2017). Functionally, homeostasis-related affects handle the animal's behavioural responses to already occurring challenges and damages in bodily functioning that immediately endanger physical fitness or survival. These affects are mostly negatively valenced, although their opposites, such as 'contentment' from tasty food or thermal comfort, can be affectively positive (Berridge, 2000). The emotional affective states, in contrast, guide the animal in choosing appropriate behavioural strategies to prosper in mid- and long-term survival and in reproduction by avoiding potential threats (Stankowich and Blumstein, 2005; Trimmer et al., 2008) and discovering opportunities relevant to its individual development (Renner, 1988; Freund et al., 2015). Thus, emotional affects and derived cognitive emotional states can be negatively (fear/anxiety, rage/anger, panic/grief) or positively (lust, fun, curiosity, sense of control, affiliative security) valenced. Appreciation of the importance of emotional affects is important in the human positive psychology literature (Seligman and Csikszentmihalyi, 2000; Fredrickson, 2003) and in the concept of QoL as applied, for instance, in human medicine (Musschenga, 1997). During the last two decades, these notions have spilled over into the area of animal welfare (McMillan, 2000; Špinka and Wemelsfelder, 2011), with the idea that positive feelings arise when animals undertake rewarding goal-directed behaviours (Hagen and Broom, 2004; McGowan et al., 2014; Mellor, 2015b).

Premise 3: There are potentially 'wider'/'hidden' benefits associated with or causally related to positive welfare

The concept of animal welfare has always encompassed both physical and mental health. For example the Five Freedoms covers freedom from pain, injury and disease (FAWC, 2009). Welfare has been defined as where an animal is 'fit and happy' (Webster, 2005) and Dawkins (2008) suggests that animal welfare can be defined in terms of whether animals are 'healthy' and 'have what they want'.

More recently the idea that positive feelings may promote health (and possibly also productivity) has created increased interest in seeking wider benefits of positive welfare and has encouraged investigation into how improvements to animal welfare can be of benefit to humans as well as animals (e.g., Christensen et al., 2012; Dawkins, 2012). The possibility that positive animal welfare may have physical health benefits emerges in part from the human literature where certain associations between positive affect and physical health have been reported (e.g., Cohen and Pressman, 2006) although the causality of different associations between positive affect and health in humans remains a topic of ongoing debate (e.g., Friedman and Kern, 2014). Similarly, an association between positive affect and longevity has been claimed for primates (e.g., 'Happy orang-utans live longer': Weiss et al., 2011) and there is evidence from rodents to support links between positive affect, enhanced synaptic plasticity and resilience to depression (Burgdorf et al., 2017).

Premise 4: There is a need for re-defining animal welfare to encompass positive welfare and to push forward the debate over animal welfare

It follows from Premises 1 to 3 that there has been a developing impetus behind extending current animal welfare frameworks to better encompass positive welfare.

Here we summarise six published propositions on positive animal welfare. Some other influential papers are not included as they do not address the whole breadth of positive welfare; for example we have not included Boissy et al. (2007) and Mendl et al. (2010) as these papers are primarily aimed at integrating understanding of animal emotions.

'*Quality of life in animals*' (McMillan, 2000). This review is, to our knowledge, the first systematic transfer of the QoL concept from humans to nonhuman animals. Although not using the term positive welfare, McMillan (2000) discusses QoL as a multidimensional experiential continuum in which 'better QoL refers to preponderance of pleasant rather than unpleasant affect in one's life over time'. Based on the QoL concept used in human medicine, needs satisfaction, health, control, social relationships and (absence of) stress are identified as elements of animal QoL.

'*Assessment of positive welfare: A review*' (Yeates and Main, 2008): In addition to covering the assessment of positive welfare, this review suggests that approaches to facilitating positive welfare could be based on concepts of 'human happiness' (e.g., Seligman et al., 2005). Based on human studies, the authors propose that animals should have a pleasurable life, an engaged life and a meaningful life. In attempting to link these human-based concepts to animals, the authors provide examples of positive and negative outcomes associated with the animal equivalents of pleasures, environmental engagement and realisation of goals.

'Farm Animal Welfare in Great Britain: Past, Present and Future' (FAWC, 2009): This report presents a future vision based on a QoL conception with three levels: 'a life not worth living', 'a life worth living' and 'a good life'. In a similar vein to Yeates and Main (2008) it suggests that future thinking on-farm animal welfare should move beyond conventional incremental improvements and consider more dramatic improvements in order to ensure a life worth living for every farm animal and a good life for a growing number of farm animals. It proposes enhancing welfare through increasing opportunities for 'comfort', 'pleasure', 'interest' and 'confidence'. There is no explanation in the report for the origin or choice of these four 'good life' opportunities.

'*Effectiveness in humans and other animals: A common basis for well-being and welfare*' (Franks and Higgins, 2012): This chapter is based on an 'effectiveness' theory of human motivation (Higgins, 2011). This theory posits that people are motivated to be effective in achieving desirable outcomes ('value effectiveness'), in establishing what is real ('truth effectiveness') and in managing what happens ('control effectiveness'). According to the authors, both human well-being and animal welfare are highest when all three effectiveness processes work together, thus creating an 'organisational effectiveness'. Thus, good QoL for an animal results from a combination of effective biological, behavioural and psychological (i.e., cognitive and affective) functioning.

'*Towards a "good life" for farm animals: Development of a resource tier framework to achieve positive welfare for laying hens*' (Edgar et al., 2013): This paper combines a study of positive welfare in laying hens with the introduction of a Resource Tier approach, analogous to the animal welfare tiers approach used in various marketing schemes such as Beter Leven and Global Animal Partnership standards. It builds on the FAWC (2009) report by discussing animal welfare in relation to the four 'good life' opportunities. An additional opportunity; 'Healthy Life', was included to achieve a balance between animals being healthy and 'having what they want' (Dawkins, 2008). The next stage was to use available literature and expert opinion to provide a relative ranking of resources in order to create three tiers of increasing welfare ('good life' levels: welfare+, welfare++, welfare+++) for each of the five good life opportunities ('comfort', 'pleasure', 'interest', 'confidence' and 'healthy life'). Twelve laying hen units were then assessed for compliance with criteria for the good life tiers. Finally, the authors propose 13 generic principles within the 5 'good life' opportunities which they argue could be applied to all types of farm animals, such as the ability to exercise individual preferences for food ('pleasure') and thermal environment ('comfort') or to have positive experiences with people and social group members ('confidence').

'Moving beyond the "Five Freedoms" by Updating the "Five Provisions" and Introducing Aligned "Animal Welfare Aims"' (Mellor, 2016a): This paper should be seen in the context of a series of reviews on positive welfare (e.g., Mellor, 2015b, 2016b) and acts as a bridge to other frameworks including the one used to create the Welfare Quality (WQ) principles (e.g., Blokhuis et al., 2010). The main features of the approach are that: (1) it focuses on provisions to support good welfare; (2) the provisions include the four WQ principles of 'Good nutrition'; 'Good environment'; 'Good health'; 'Appropriate behaviour' to which a fifth, 'Positive mental experiences', is added; (3) it aligns the provisions with welfare aims to minimise negative and maximise positive experiences (e.g., provision: 'Good environment'; welfare aim: 'Minimise discomfort and exposure and promote thermal, physical and other comforts'); (4) the exception to this is the fifth provision which is directed solely at promotion of the positive experiences of 'comfort, pleasure, interest, confidence and a sense of control'; (5) it emphasises the importance of promoting engagement in behaviours that are rewarding through active interactions with the environment, a theme that is covered in greater detail by Mellor (2015a, 2015b).

In summary, these approaches to positive welfare have important commonalities and distinctions:

1. Yeates and Main (2008) and Franks and Higgins (2012) base their positive welfare framework partly on the work of Seligman and colleagues from the field of positive psychology (e.g., Seligman et al., 2005; Seligman and Csikszentmihalyi, 2000). (FAWC (2009) do not indicate the origin of their 'good life opportunities' (comfort, pleasure, interest, confidence) but these terms are found in the positive psychology literature (e.g., Scorsolini-Comin et al., 2009) suggesting that positive psychology had some influence on their use by FAWC. Edgar et al. (2013) adopted these terms for their Resource Tier approach.). McMillan (2000), FAWC (2009), Edgar et al. (2013) and Mellor (2016a,b) draw from the QoL concepts developed in human medicine and sociology (Musschenga, 1997) albeit from two different perspectives. While McMillan (2000) stresses the multidimensional character of QoL, FAWC (2009), Edgar et al. (2013) and Mellor (2016b) use it for proposing that QoL be organised in tiers of ascending animal welfare status, with the extremes being 'a life not worth living' vs 'a good life'.

2. The frameworks vary in how they view the primacy of motivation and affect in relation to QoL. Yeates and Main (2008) draw upon the work of Berridge and colleagues (e.g., Berridge and Robinson, 2003) to make the distinction between what animals ‘want’ (motivation) and what animals ‘like’ (affect). They admit that wanting and liking usually go hand in hand but note that there are occasions when animals may perform motivated behaviours that deprive them of future pleasures or cause long-term harm. McMillan (2000) proposes that QoL is concerned exclusively with affect, while Franks and Higgins (2012) promote the primacy of motivation, of which affective experience is part, in their view. FAWC (2009) and Edgar et al. (2013) do not mention a motivation vs affect distinction.
3. The frameworks also vary as to the required balance for a good QoL, between more homeostatic-based ‘needs’ (or necessities) and ‘other needs’ that have also been termed wants or desires. Although the terminology varies across the frameworks (needs vs wants (FAWC, 2009), needs vs desires (McMillan, 2000), survival-critical vs situation-related affects (Mellor, 2016a), harm-preventing vs positive-welfare-facilitating needs (Edgar et al., 2013)), the basic contrast remains the same and matches well with the above described functional distinction between homeostasis-related and emotional affects. Yeates and Main (2008) quote a distinction between vital vs substitutable needs but they see both on a continuum of motivational strengths achieving different outcomes, with the possibility to assess the continuum on a sliding scale from ‘completely inelastic’ to ‘elastic’ based on consumer demand theory (e.g., Matthews and Ladewig, 1994). The frameworks vary as to the balance between ‘needs’ and ‘desires’ required for a good QoL. McMillan (2000), FAWC (2009) and Edgar et al. (2013) agree that meeting all homeostatic-based needs is essential for an ‘acceptable’ QoL or ‘life worth living’ (FAWC, 2009) and that fulfilment of all desires is not necessary for high QoL. FAWC (2009) specifies that a ‘life worth living’ requires provision of ‘certain wants’ while for a ‘good life’, provision of ‘more wants’ is needed. Yeates and Main (2008) and FAWC (2009) warn that meeting of some wants may be detrimental to the animal (Yeates and Main, 2008; FAWC, 2009) and Mellor, (2016a) agrees that only harmless wants should be provided for. Franks and Higgins (2012) seem to put less value on needs satisfaction, suggesting that good welfare can be collected under the heading of effectiveness. For Franks and Higgins (2012), the ability of the animal to respond appropriately to challenges and opportunities is more important for its welfare than the absence of stress, disease and negative emotions or the presence of positive emotions per se. In spite of the differences, all six frameworks propose that desire fulfilment plays a constituent role in positive welfare, be it under the headings of ‘control’ and ‘social relationships’ (McMillan, 2000), ‘engaged life’ and ‘meaningful life’ (Yeates and Main, 2008), ‘interest’ and ‘confidence’ (FAWC, 2009; Edgar et al., 2013), ‘truth effectiveness’ and ‘control effectiveness’ (Franks and Higgins, 2012) or ‘appropriate behaviour’ (Mellor, 2016a).
4. Somewhat different solutions to assessing positive welfare are proposed. While there is general agreement that animal-based outcome measures provide the preferable direct assessment of positive welfare, they are often difficult to standardise and record, especially if the outcomes are behavioural or even mental. Resource-based measures are more practicable and may be easier for farmers to accept. Therefore Edgar et al. (2013) focused solely on provision of resources in their multi-farm empirical study. Both Yeates and Main (2008) and FAWC (2009) promote combinations of resource-based and outcome-based measures. Mellor (2016a) in his Five Domains model specifically proposes to measure two domains (Nutrition, Environment) through resources and three domains (Health, Behaviour, Mental State) as outcomes. One can argue that

resource-based criteria are practical proxy measures that require validation by outcome-based criteria.

Having reviewed general approaches to positive welfare it is now relevant to look more specifically at developments in positive welfare with respect to pigs. We address three areas: animal-based approaches available to assess positive welfare in pigs; empirical knowledge about current positive welfare status quo in modern pig production; and prospects for promoting pig positive welfare.

15.3 Measuring positive welfare in pigs through behavioural indicators

Although resource-based measures are important for practical assessment and progress in positive welfare, here we focus on outcome-based measures as they are conceptually and methodologically more challenging yet much needed for validation of resource-based provisions. Even more strictly, we limit this overview to behavioural measures as they are the closest proxies to positive affective states and motivations that ultimately matter for the animal. Without attempting to be exhaustive, we describe six methods that fall into three categories: quantitative recording of spontaneously occurring behaviours (using play behaviour and affiliative social behaviour as exemplars), staged tests (preference testing, consumer demand and judgement bias) and qualitative behavioural assessment (QBA).

15.3.1 Spontaneously occurring behaviours

Here we refer to behaviour occurring spontaneously in the 'home pen' or other living environments (i.e., not stimulated by test conditions). There is a rich history of behavioural observations in domestic pigs stretching back to the origins of the animal welfare debate. There has been ample discussion of the importance for welfare of 'natural' or 'normal' behavioural expression (e.g., Fraser et al., 1997; Bracke and Hopster, 2006; Špinka, 2006). Although much of the debate has been over the negative effects of preventing strongly motivated behaviour such as nesting behaviour (e.g., Brambell, 1965), it has also been proposed that many natural behaviours are associated with positive affective states. Here we cover play and social affiliation as two prominent behavioural patterns that appear to indicate that pigs feel good when they perform them, but also promote other facets of positive welfare and thus can be viewed as 'beneficial wants' and used as indicators of positive welfare (We have already described the rather different ways that the term 'want' is used in the positive welfare literature. Here we refer to wants in the same way as McMillan (2000) and FAWC (2009) to mean low priority or non-essential motivations; beneficial wants have few associated negative outcomes.).

15.3.2 Play behaviour

Play behaviour is only expressed under currently non-life-threatening conditions. Playing animals appear pleasurably excited yet relaxed, giving the overall impression that they are having fun (Špinka et al., 2001). At the psychological level, play could be conceived as reflecting an emotional state of elevated arousal and positive valence (see Mendl et al., 2010). At the neurobiological level, the feelings of joy accompanying mammalian play behaviour may be generated by a primary (i.e., unconditioned) emotional system of the brain that evolved specifically as the affective motivator of play (Panksepp, 2011). Opportunities for social play serve as rewards in T-maze, conditioned place preference and operant conditioning paradigms, at least for juvenile rats (e.g., Humphreys and Einon, 1981; Calcagnetti and Schechter, 1992; Achterberg et al., 2016) demonstrating that animals are motivated to play. Based on the interpretation that play is motivated behaviour associated with positive feelings and occurs when there is an absence of threats to fitness, it was identified by Boissy et al. (2007) as one of the most promising indicators for assessing positive welfare (see also Lawrence, 1987).

In a review on animal play and animal welfare, Held and Špinka (2011) identified four aspects through which performance of play by animals can indicate their positive welfare. First, play indicates a favourable environment because animals tend to reduce play when they are experiencing challenges and even abolish play when their fitness is under threat. Second, play indicates the presence of neurotransmitter-mediated pleasurable affective experience. Third, play may contribute to the animal's bodily, cognitive and affective competence and resilience, thus improving chances for positive welfare in the future. Finally, because of its contagious nature, play could be an indicator of good social functioning in group housed animals. In the following paragraphs, we briefly review the evidence for the first and the third play-welfare association in pigs (play indicates better environment; play builds capacity for future welfare) and omit the other two as scientific data on them in pigs are either missing altogether (neurobiology of play) or very limited (contagiousness – Reimert et al., 2014).

Across environmental conditions predicted to affect welfare, the available results tend to confirm that pigs play more in better conditions. To illustrate, brief suppression of play was observed under conditions such as bad weather (Newberry et al., 1988) and abrupt separation from the sow at weaning (Donaldson et al., 2002; Martin et al., 2015) and more fleetingly when pigs were exposed to playback of adult alarm barks (Chan et al., 2011). Piglets tended to play more in straw-bedded farrowing pens (Chaloupková et al., 2007), and played significantly more in a free-farrowing pen (PigSAFE; Martin et al., 2015), than in smaller slatted-floored farrowing crates that confined their mother's movements. Furthermore, piglets remaining with their own mother engaged in more social play than fostered piglets (Martin et al., 2015). After weaning, pigs in straw-bedded pens played over three times more than pigs in slatted-floored pens (Bolhuis et al., 2005) and pigs housed in 4 ppm ammonia concentrations played twice as much as pigs living in 20 ppm concentrations (Parker et al., 2010). Enrichment of housing with straw, bark and tree branches also increased the frequency of scampering by pre-pubertal gilts compared to that observed in substrate-impoverished housing (Haskell et al., 1996). In summary, the evidence indicates that if two or more living environments of pigs are compared, the amount of spontaneous play can serve as an indicator of positive welfare differences between them.

The iniquitousness of play in young mammals implies evolved short-term and/or long-term functional benefits (Špinka et al., 2001; Held and Špinka, 2011) but evidence is so far patchy for domestic pigs. One hint of a potential benefit in pigs comes from the observation of a more rapid recovery of social play following weaning in pigs that had more social play experience prior to weaning, suggesting that the play experience may have enhanced their emotional resilience (Donaldson et al., 2002). Additionally, when played back at weaning, sound cues previously associated with the opportunity for play were sufficient on their own to stimulate some play, suggesting that anticipation of play moderated weaning stress (Dudink et al., 2006; de Jonge et al., 2008a). Martin et al. (2015) observed that piglets that played more prior to weaning due to being reared in environmentally more complex farrowing pens resolved their post-weaning, post-mixing aggression quicker and also were better at discriminating familiar and novel objects. However, it was impossible to distinguish whether these positive effects were caused by the increased amounts of play or by other aspects of the more complex pre-weaning environment. In a similar vein, Chaloupková et al. (2007) found that piglets reared before weaning in an enriched pen played more during that period and also fought much less during 20 min food competition tests at 3 and 6 months of age, but it was impossible to conclude whether the two phenomena were causally related. At the level of individual piglets, performance in tests of object recognition memory post-weaning was predicted by higher pre-weaning piglet-sow play levels but not by total play levels (Martin et al., 2015). In summary, gaining a clearer picture of the impact of play on fitness correlates remains a key topic for evaluating the validity of play as an indicator of positive welfare.

Given the indications that play behaviour may be a valid indicator of positive welfare in pigs, the question remains of how reliable a measure it could be. In other words, how strong is the 'signal' about positive welfare in proportion to the background 'noise' variability in play? The variability in recorded pig play levels is huge, whether it is quantified on individual, litter, or farm level (Brown et al., 2015; Šilerová et al., 2010). The signal-to-noise ratio of the indicator could be improved by accounting for other known factors that may systematically affect play levels, especially stable interindividual differences, age and sex.

There is evidence of persistent individual differences in playfulness, with certain individuals being more likely to engage in play than others. Brown et al. (2015) observed that 11% of the variance in play was attributable to differences between piglets within litters. This was less than the variance attributable to differences between litters (50%), perhaps due in part to contagion of play among litter members. Playful movements such as scampering and pivoting, and accompanying visual and vocal signals such as tail wagging and barks (Newberry et al., 1988; Chan and Newberry, 2011; Reimert et al., 2015), may have a contagious effect on others. Hence, a higher level of play within a group may arise as a consequence of the relatively playful personality of certain individuals, although Reimert et al. (2015, 2017) did not find clear evidence for contagion of positive emotion in controlled experiments. Interindividual differences in playfulness may also be related to other stable individual characteristics such as coping styles measured in young piglets by restraining them on their backs (Bolhuis et al., 2005).

Play is characteristic of pre-pubertal pigs and varies in amount and composition with age and sex. Newberry and Wood-Gush (1988) observed peaks of locomotor play (scampering) between 2 and 4 weeks of age and social play (circling and shoving) between 4 and 6 weeks of age, while carrying and shaking objects (object play) occurred at low levels throughout. Various reports suggest that females perform (proportionally or absolutely) more locomotor play than males (e.g., Rauw, 2013; Brown et al., 2015; Martin et al., 2015) whereas males engage in and initiate more play fighting (e.g., Brown et al., 2015) and play mounting (Berry and Signoret, 1984). As for the total amount of play, various studies report more play in females, in males or no statistically significant difference (e.g., Bolhuis et al., 2005; Rauw, 2013; Brown et al., 2015; Martin et al., 2015). More than 30 empirical papers have been so far published on pig play. A meta-analysis of these data might help to determine factors affecting the timing and shape of peaks in different forms play and could guide additional long-term studies that would trace the ontogeny of different forms of play and relate them to measures of fitness.

In terms of methodology, play has the advantage that it is often easy to recognise. Play behaviour is characterised by exaggerated, awkward movements that appear self-handicapping. In pigs, movements that appear playful include hopping, scampering (bouncy running), pivoting (hopping around to face in a different direction), head tossing (sweeping the head from side to side), carrying objects in the mouth and shaking objects, leading Newberry et al. (1988) to use these behaviours as 'markers' of playful behavioural sequences. Other behaviours such as butting and shoving are the main components of social play but they also occur in the context of aggressive fights that result in bite wounds and their motivational basis can be ambiguous and thus they cannot be considered true play markers. Nonetheless some studies do report on non-harmful play fighting (e.g., Brown et al., 2015; see also Pellis and Pellis, 2016). A further challenge to categorising play is that play may take different forms in different environments. For example, playfully flopping from an upright to prone position was not recorded in the Edinburgh Pig Park but occurred sufficiently often in small, indoor pens to feature in Donaldson et al.'s (2002) play ethogram. Due to inconsistencies in play ethograms (which may also arise from differing hypotheses about the function(s) of play), variation in the methodology used to quantify play must be kept in mind when interpreting results across studies.

Play behaviour takes up only a small proportion of the behavioural time budget and therefore data collection on spontaneous play is time-consuming. Consequently, researchers have sought methods for reliable induction of play during brief observation periods. Play can be reliably stimulated by repeatedly releasing pigs from their home pen into a larger environment, especially if it is enriched by straw, food treats or novel objects (Wood-Gush and Vestergaard, 1991; Donaldson et al., 2002;

Dudink et al., 2006). Elevated play reported under these conditions may be interpreted to represent a 'relief' response to recent stress (e.g., rebound after weaning), a coping response under conditions of mild anxiety (e.g., in the presence of a novel object), or an 'elation' response to the positive contrast of the stimulating play arena with a more monotonous home environment. While increased play under these conditions may contribute to stress resilience and so be a factor for better welfare, it is not necessarily reflective of positive welfare in the home pen.

It can be concluded that a better understanding of the variability, mechanisms, ontogeny and adaptive value of play in pigs is needed to assess its specificity and sensitivity as an indicator of positive welfare. Longitudinal studies in which play is stimulated or suppressed in specific individuals would be useful for tracing effects of play on those individuals and other members of their group. Further, knowledge generated by finegrained analysis of play movements (e.g., Petrů et al., 2008) could be used to train automated systems (e.g., see Šustr et al., 2001) to decipher playful patterns from sequences of biophysical electronic data (e.g., from three-dimensional accelerometers, video images, heart rate monitors, etc.), leading to the development of reliable and efficient play evaluation protocols for on-farm use.

15.3.3 Social affiliative behaviour

Domestic pigs are social animals and when kept outdoors, adopt a social structure similar to that seen in their wild relatives by forming small groups of sows and piglets (see Stolba and Wood-Gush, 1989). Social behaviour has received a lot of attention in pigs but particularly in relation to negative outcomes such as aggression and tail-biting (see Verdon and Rault, 2017 Chapter 8: Aggression in group housed sows and fattening pigs; Valros, 2017 Chapter 5: Tail biting). Affiliative behaviours, including allogrooming, have been proposed as potentially important contributors to positive emotional states in animals (Boissy et al., 2007). Pigs do not allogroom each other through mutual licking, but one recent study has looked in detail at the characteristics of social nosing and its relationship to other behaviours (Camerlink and Turner, 2013). Social nosing was defined as gentle pig-directed nosing behaviour of the head and body, and it was largely unrelated to harmful behaviours (e.g., biting of tails) and was not directly related to social dominance. The function of social nosing remains open to speculation but there is evidence that its massaging effect can have positive physiological sequelae (Hansen and von Borrell, 1999 cited in Boissy et al., 2007). Social nosing has also been shown to correlate positively with growth rate (Camerlink et al., 2012).

Another aspect of social behaviour which has been gaining attention and has relevance to positive welfare is referred to as social support or social buffering and covers the phenomenon whereby animals (including humans) recover better from distress in the presence of conspecifics (Kikusui et al., 2006; Rault, 2012). There is some evidence that pigs can also benefit from the presence of another familiar pig during a stressful event (Reimert et al., 2014) and that social buffering in piglets is associated with changes in gene expression in different brain regions (Kanitz et al., 2016). There seems to have been no specific study in pigs of the role of social support in the absence of environmental stressors, although a recent paper illustrates a potential role for oxytocin in the maintenance of positive interactions between humans and pigs (Rault, 2016).

In terms of practical uses, as far as we are aware, no current assessment protocol for pig welfare uses measures of positive social interactions directly. However, assaying which pigs chose to engage in activities together such as rubbing and scratching, drinking water, sniffing a person, sniffing unusual objects, sniffing and playfully butting each other, grunting in close succession, and resting together provides clear evidence of their affiliative relationships (Newberry and Wood-Gush, 1986). Moreover, assessing the level of behavioural synchronicity in groups of pigs is relevant given hypothesised ties to a sense of security and cohesion (Špinka, 2012), with the potential for enhancement of positive affect within and across groups through contagion as observed in humans (e.g., Fowler and Christakis, 2008). Thus, determining both the social connectedness of individual pigs and overall group cohesiveness through network analysis may be useful as a positive welfare assay in future. The advent of selection for social genetic effects in production traits such as growth (Canario et al., 2012) and reproductive performance (Bunter et al., 2015) may indirectly select for pigs expressing more positive social behaviour if this is correlated with the selection goal of reducing the impact of negative behaviours such as aggression and tail-biting on the production traits (Canario et al., 2012).

15.3.4 Behavioural tests

15.3.4.1 Preference testing and consumer demand

Preference testing was the first ‘test-based’ approach to assessing animal welfare pioneered in early welfare research (e.g., Dawkins, 1977). It is based on the assumption that we can utilise what animals find positively or negatively reinforcing (as expressed through their preferences or choice behaviour) to establish which resources might induce positive and negative emotional states (e.g., Dawkins, 2008). Consumer demand testing is a further development of the approach which aims to assess the strength of motivation underlying preferences (Dawkins, 1990).

Preference testing and consumer demand were developed to scale ‘behavioural needs’ (Dawkins, 1983; Hughes and Duncan, 1988) or ‘what animals want’ (e.g., Dawkins, 2008) against a ‘hard currency’ of resources necessary for fitness (e.g., food). This focus on ‘needs’ has been criticised, initially on the basis of whether a focus on strongly motivated needs was the correct approach to improving welfare as opposed to a focus on less motivated ‘luxury’ behaviours (Lawrence, 1987). More recently Yeates and Main (2008) pointed out that instead of traditional attempts to dichotomise between outcomes that are fundamental for the animal and those that are not, one can compare motivational strengths on a continuum and thus include positive welfare considerations.

Preference tests, and to a lesser extent consumer demand, have been used to define behavioural motivation of pigs for space, rooting materials, social companionship and thermal comfort (e.g., Jensen et al., 2008; Matthews and Ladewig, 1994; Pedersen and Jensen, 2007). Pigs have been shown to contrafreeload (i.e., ‘work’ to obtain resources that are also available freely) in a foraging task (de Jonge et al., 2008b; but see Young and Lawrence, 2003), which has been interpreted in terms of positive anticipation of reward. Further, in their RICHPIG model, Bracke et al. (2006) take the position that preference and demand equate to positive welfare. Preference testing (including the derived methodology of conditioned place preference) and consumer demand approaches have proven to be useful tools in research on motivation and behavioural neurobiology. Their relevance and utility for positive welfare assessment deserve further investigation.

15.3.4.2 Judgement bias tests

More recently, researchers have proposed a set of variations on what are referred to as 'judgement' or 'cognitive' bias tests as an approach to assessing emotional state and mood in animals. The core idea, based on human research, is that as emotional state influences cognitive processes then animals' cognitive processing can be used to infer their underlying emotional state. The approach generally involves conditioning animals to stimuli indicating reward or punishment, and then testing with ambiguous stimuli to see if animals respond to these 'optimistically' or 'pessimistically' (an optimistic bias interpreted to indicate a positive underlying emotional state; a pessimistic bias the reverse; e.g., Harding et al., 2004; Mendl et al., 2009; Mendl et al., 2010). Several studies have assessed judgement bias in pigs, the majority directed at assessment of factors inducing negative emotional states. However, Douglas et al. (2012) investigated the effect of an enriched environment in a small sample of gilts and found it to be associated with optimistic judgement bias. Furthermore, they found that moving the gilts from an enriched to a barren environment induced a more negative reaction to barren housing than when experiencing only barren housing.

15.3.4.3 Qualitative behavioural assessment

QBA arose from the position (partly philosophical and partly biological) that it can be legitimate to study animal behaviour from a qualitative perspective (e.g., Wemelsfelder, 2012). QBA focuses on the expressive quality of the behaviour as opposed to the physical characteristics of behaviour that are usually recorded (Wemelsfelder et al., 2000). An innovative step was to qualitatively assess animal behaviour through free-choice profiling (FCP). FCP allows observers to develop their own qualitative terminology to collect qualitative descriptions of behaviour which are then statistically analysed using generalised procrustes analysis (Wemelsfelder et al., 2001).

Much of the development and validation of the QBA approach has been conducted on pigs (e.g., Wemelsfelder et al., 2000, 2001). Two important developments are worth emphasising. Firstly in terms of scientific validation, Rutherford et al. (2012) demonstrated that observers using QBA were able to detect qualitative differences in pigs exposed to anxiogenic conditions (an open field or elevated plus maze), where pigs were previously injected with an anxiolytic (anxiety reducing drug) or a saline control. In other words, observers were sensitive to the behavioural changes induced by pharmacological treatment of anxiety. Secondly, in the WQ project, QBA was selected as the only reliable and validated measure of positive emotional state in all species including pigs (Welfare Quality, 2009). QBA has subsequently been applied in studies to assess on-farm pig welfare (Mullan et al., 2011; Temple et al., 2011).

In summary, there are a number of approaches that have been proposed for the assessment of positive welfare in pigs. For some of these (e.g., aspects of spontaneous behaviour; preference tests) there is a need for further work to confirm their validity as measures of positive welfare. Others (judgement bias tests and QBA) have a stronger theoretical link to the concept of positive welfare but few papers have applied them to questions of positive welfare to date.

15.4 Positive pig welfare in the real world

Pigs are unique in having had a housing system developed entirely on the basis of observations of their natural behaviour. The Edinburgh Family Pen System was designed around observations made of family groups of pigs living in a semi-wild enclosure with the aim of replicating key conditions required for the stimulation of the behaviour patterns observed under 'unconstrained conditions' (Stolba and Wood-Gush, 1984, 1989). Although the Edinburgh Family Pen System failed to become a commercial reality, it remains a totemic example of the principle of allowing farm animals to live natural lives whilst in a commercial environment. With its focus on facilitating species-typical behaviours such as exploration, foraging, and maternal and neonate behaviours through providing a generous and structured space with substrates, it could be argued that the Family Pen System was facilitating positive welfare through all the 'good life opportunities' envisioned in the recent frameworks. Interestingly, there is no reference to positive welfare terms such as positive emotions or pleasure in the original papers (e.g., Stolba and Wood-Gush, 1989), which reflects that the work was conducted in the 1970s–80s when there was little direct discussion of animal emotions (and particularly positive emotions) in animal welfare science. The question to be addressed here is to what extent modern pig production caters for positive welfare of pigs.

As far as we are aware, there is only one study to date that has analysed current pig farming conditions against a set of descriptors of positive welfare. Mullan et al. (2011) aimed to establish the extent to which UK pig producers went beyond minimum UK legal standards and welfare codes. This study was foundational to the Resource Tier approach (Edgar et al., 2013). It was based on the simplifying assumption that positive welfare starts when provisions exceed legal requirements and welfare codes. Pig keeping descriptor scores, based on legislation and existing welfare recommendations, were agreed in consultation with stakeholders. The descriptors covered the areas of environmental enrichment, foraging behaviour, thermal and physical comfort, tail docking and floor space provision. Pig finisher farms were scored on the extent to which they met and exceeded the legal requirements for the descriptors.

A complication for the study was the interpretation of the discrepancies between the UK legislation and the welfare code requirements. For example, interpretation of the legislation implied that a manipulable object alone would be unsatisfactory in satisfying the pigs' behavioural needs. However the guidance given by the welfare code (DEFRA, 2003) appeared to allow for some use of 'toys' such as balls and chains as the sole enrichment (Mullan et al., 2011, 447). In the case of foraging behaviour, neither the legislation nor welfare codes were specific in terms of foraging behaviour requirements beyond providing wholesome food. It is interesting to reflect upon which extra resources, over and above a single manipulable enrichment, can be practically offered to satisfy foraging in pigs. For example, Young et al. (1994) proposed the use of a foraging device (The Edinburgh Foodball) for this purpose. The results of Mullan et al. (2011) are summarised in Table 15.1. All 15 farms in the study complied with legislation with the possible exception of the provision of enrichment. However, a majority of farms did not meet the higher standards of welfare provision established at the outset of the study. As an example, in relation to enrichment, nine of the farms only provided a single manipulable object (with no other enrichment as recommended in the welfare code) and gave no information on whether this object was regularly changed (as also recommended in the code). Of the six farms that provided straw, they did so either in the form of deep bedding or by the 'straw-flow' system.

This pilot work by Mullan et al. (2011) clearly needs expanding. However, it does reflect our experience that the majority of global commercial pig production units fall short in terms of promoting positive pig welfare. For example, if we assume that species-typical behaviours such as exploration, foraging, play, nesting and maternal−offspring interactions are largely synonymous with positive welfare (Bracke and Hopster, 2006; Špinka, 2006), then most pig production facilities around the world fail to provide adequate opportunities for their expression.

Table 15.1 Summary of a study of pig finisher units ($n = 15$) exceeding standards set by legislation and welfare codes. Farms were scored on 6 'positive system descriptors' on a scale of 1−5 (1: meets legal requirements; 2: meets UK welfare code recommendation; 3−5: progressive increases in 'welfare provision') (Mullan et al., 2011).

Positive system descriptors	Numbers of pig finisher units achieving Scores 3 and higher (i.e., exceeding legal requirement or welfare code) (% in brackets)
Environmental enrichment	6 (40)
Absence of tail docking	0 (0)
Space	1 (7)
Thermal comfort	1 (7)
Physical comfort	9 (52)
Foraging behaviour	3 (20)

Similarly it is our contention that most intensive pig production systems globally do not provide sufficient levels of enrichment materials to facilitate substantial expression of behaviours such as exploration (see Pedersen et al., 2014 and below).

15.5 What does positive welfare add to the debate over pig welfare?

Finally we would like to suggest ways in which the concept of positive welfare potentially adds to the debate over pig welfare.

15.5.1 Raising the bar

As a concept, animal welfare accepts the use of animals by humans, and as much of the focus has been on-farm animal welfare, inevitably 'practical' and 'commercial' aspects cannot be ignored. Indeed there has been a growing interest in the use of economics to better understand how to improve animal welfare in the context of other competing issues (e.g., Christensen et al., 2012).

One approach to improving welfare that takes account of the difficulties of improving welfare in the 'real world' is to consider the minimum improvements required to reduce negatives or 'harms', for example the minimum enrichment required to reduce tail-biting in growing pigs. D'Eath et al. (2014) concluded on the basis of an analysis of the available literature that a small amount of destructible material such as straw (perhaps as little as 10 g/pig/day; see also Zonderland et al., 2008) could have beneficial effects in reducing tail-biting.

An alternative would be to consider the amount of a resource (or other input) required to maximise a positive welfare outcome. For example Pedersen et al. (2014) studied the effect of an increasing allocation of straw on exploratory behaviour in pigs and concluded that the inflection point (beyond which extra straw provision had a diminishing effect on exploratory behaviour) was at around 250 g/pig/day. Thus these different approaches, one aimed at reducing harms and the other aimed at maximising positives can potentially end up with quite different solutions (see Fig. 15.2).

In effect this is the same argument behind the Resource Tier approach. Edgar et al. (2013) suggest that considering which resources are required to maximise positive welfare outcomes is likely to be more radical in terms of welfare improvements than traditional harm reduction approaches.

15.5.2 New areas for biological discovery

Positive welfare has the potential to open up new channels of science discovery. There are increasing examples of research on positive psychology in nonhuman primates (e.g., studies of subjective well-being in chimpanzees; King and Landau, 2003), and in the neurobiology underlying positive emotions (e.g., Burgdorf and Panksepp, 2006; Burgdorf et al., 2017). However, there has been relatively little

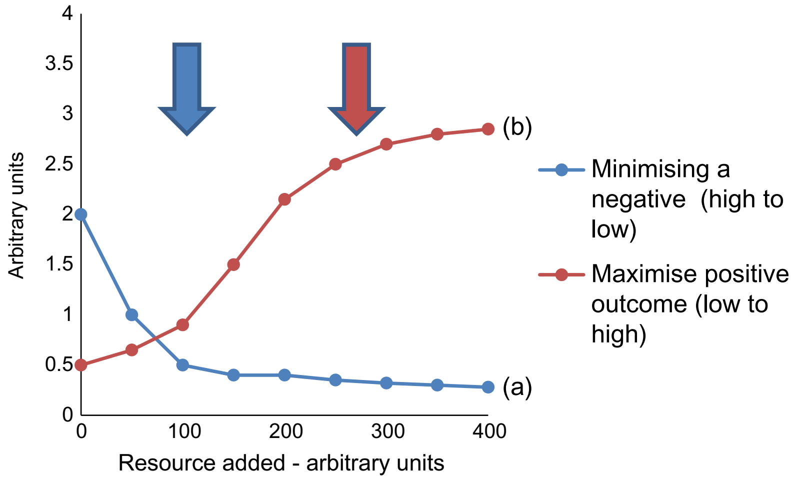

Figure 15.2 Hypothetical example of approaching welfare improvements on the basis of aiming to: (a) minimise a negative (harm); (b) maximise a positive outcome. The *x* axis represents arbitrary units of a resource that can achieve either (a) or (b) (e.g., straw to (a) reduce tail-biting; (b) act as a stimulus for exploration). The *y* axis shows the effect of the amount of the resource in terms of (a) minimising a negative outcome (e.g., tail-biting); (b) increasing a positive outcome (e.g., exploratory behaviour). The downward arrows indicate the approximate 'efficient provision' points where thereafter additional amounts of the resource result in only negligible returns. In this hypothetical example, the efficient point for maximising a positive outcome (red) requires at least double the resource input compared to minimising a negative outcome (blue). This concept is based on actual data from experiments on straw provision (see D'Eath et al., 2014; Pedersen et al., 2014).

research on the biology of positive psychological states in farm animals such as pigs and also the wider implications of positive welfare to other 'body systems'. A recent example illustrates a potential new line of research into wider health implications of positive welfare as elicited by environmental enrichment. Dixhoorn et al. (2016) demonstrated that pigs in 'enriched' housing prior to infection with porcine reproductive and respiratory virus (PRRSV) were less susceptible to PRRSV than barren housed pigs based on faster clearance of the PRRSV in blood serum and fewer histological signs. This work raises many interesting questions, not least being the mechanism of this reported enrichment-induced disease resistance. In addition, determining optimal conditions for promoting resilience in response to environmental change and social losses is also a relevant area for future research. For instance, rearing pigs in enriched conditions in early ontogeny may, on the one hand, build resilience capacities, but a later transfer to worse conditions may, on the other hand, induce negative affective states (see Douglas et al., 2012). Moreover, attention to pig handling systems would be fruitful. For example, instead of moving pigs by driving them away from humans, promotion of positive human–animal relationships (Tallet et al., 2017 Chapter 13: Pig-human interactions: creating a positive perception of humans to ensure pig welfare) requires rethinking of methods used to move them around within farms and especially on and off vehicles (see Faucitano and Goumon, 2017 Chapter 9: Transport of pigs to slaughter and associated handling).

15.5.3 Changing human behaviour

There is interest in the role of human behaviour as a target for agricultural sustainability interventions from farmers (Moran et al., 2013) through to consumers and citizens (Mamouni Limnios et al., 2016). Similarly there has been a growing interest in societal perceptions of animal welfare issues (e.g., Leenstra et al., 2011). Interestingly, when comparing animal welfare scientists' and societal views, it has been suggested that scientists are more focused on negative welfare aspects (suffering) relative to the public, who tend to spontaneously refer to more positive welfare aspects (Miele et al., 2011). Miele et al. (2011) suggest that this may be because the public expect that animal suffering does not or should not exist in developed countries. However, what seems to be missing from the literature is an analysis of the relative effectiveness of focusing on negatives or positives in creating behavioural change. In a meta-analysis of studies of 'willingness to pay' (WTP) for welfare improvements, there was no reference to the influence of scenario setting on the outcomes (Lagerkvist and Hess, 2011); in other words, there appears to be no investigation of whether more significant WTP would result from a strategy of small incremental welfare improvements (as in Moran and McVittie, 2008) or more radical welfare improvements (as envisaged in the Resource Tier approach). We propose that there is potential value in investigating whether including positive welfare in campaigns to promote behavioural change is more effective than a more conventional approach.

15.6 Conclusions and future developments

Positive welfare is a relatively new concept when considered from the perspective of intensive pig farming which predominates in the global production of pork meat. First, the scientific literature is predominately focused on what can be regarded as more negative aspects of pig welfare and most heavily weighted towards the last hours or days of the pigs' life. Second, whilst there are a number of approaches which could be applied to assess positive welfare in pigs, there have been few studies to date and there is a need for further validation and refinement for practical on-farm application. Third, we can find only one small study into how pig farms match up against positive welfare descriptors; this one study of finisher pigs suggests that intensive pig production methods are generally inadequate in promoting positive welfare. Finally, we make the case that a focus on positive welfare could have a number of advantages which could influence future developments in pig welfare. These include: a change of focus from making small steps to reduce negatives to more radical changes to maximise positives; discovery of new biological insights into positive emotional states and their role in promoting positive welfare; and greater effectiveness in instigating substantive human behavioural change across the supply chain in favour of improved pig welfare.

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Abbreviations

FAWC UK Farm Animal Welfare Council
OIE World Organisation for Animal Health
PRRSV porcine reproductive and respiratory virus
QBA qualitative behavioural assessment
QoL quality of life
WTP willingness to pay

References

Achterberg, E.J.M., Van Swieten, M.M.H., Driel, N.V., Trezza, V., Vanderschuren, L.J.M.J., 2016. Dissociating the role of endocannabinoids in the pleasurable and motivational properties of social play behaviour in rats. Pharmacol. Res. 110, 151–158. Available from: http://dx.doi.org/10.1016/j.phrs.2016.04.031.

Acton, H., 1961. Animal pleasures. Mass. Rev. 2, 25–49.

Baxter, E.M., Rutherford, K.M.D., D'Eath, R.B., Arnott, G., Turner, S.P., Sandøe, P., et al., 2013. The welfare implications of large litter size in the domestic pig II: management factors. Anim. Welfare 22, 219–238. Available from: http://dx.doi.org/10.7120/09627286.22.2.219.

Baxter, E.M., Edwards, S.A., 2017. Piglet mortality and morbidity: inevitable or unacceptable? In: Špinka, M. (Ed.), Advances in Pig Welfare. Woodhead Publishing, Duxford, UK.

Baxter, E.M., Andersen, I.L., Edwards, S.A., 2017. Sow welfare in the farrowing crate and alternatives. In: Špinka, M. (Ed.), Advances in Pig Welfare. Woodhead Publishing, Duxford, UK.

Bennett, R., Blaney, R., 2002. Social consensus, moral intensity and willingness to pay to address a farm animal welfare issue. J. Econ. Psychol. 23, 501–520.

Berridge, K.C., 2000. Measuring hedonic impact in animals and infants: microstructure of affective taste reactivity patterns. Neurosci. Biobehav. Rev. 24, 173–198.

Berridge, K.C., Robinson, T.E., 2003. Parsing reward. Trends Neurosci. 26, 507–513. Available from: http://dx.doi.org/10.1016/S0166-2236(03)00233-9.

Berry, M., Signoret, J.P., 1984. Sex play and behavioural sexualisation in the pig. Reprod. Nutr. Dév. 24, 507–513. Available from: http://dx.doi.org/10.1051/rnd:19840501.

Blokhuis, H.J., Veissier, I., Miele, M., Jones, B., 2010. The Welfare Quality® project and beyond: safeguarding farm animal well-being. Acta Agric. Scand. Sect. A-Anim. Sci. 60, 129–140. Available from: http://dx.doi.org/10.1080/09064702.2010.523480.

Boissy, A., 1995. Fear and fearfulness in animals. Q. Rev. Biol. 70, 165–191.

Boissy, A., Manteuffel, G., Jensen, M.B., Moe, R.O., Spruijt, B., Keeling, L.J., et al., 2007. Assessment of positive emotions in animals to improve their welfare. Physiol. Behav. 92, 375–397. Available from: http://dx.doi.org/10.1016/j.physbeh.2007.02.003.

Bolhuis, J.E., Schouten, W.G.P., Schrama, J.W., Wiegant, V.M., 2005. Behavioural development of pigs with different coping characteristics in barren and substrate-enriched housing conditions. Appl. Anim. Behav. Sci. 93, 213–228. Available from: http://dx.doi.org/10.1016/j.applanim.2005.01.006.

Bracke, M.B.M., Hopster, H., 2006. Assessing the importance of natural behavior for animal welfare. J. Agric. Environ. Ethics 19, 77–89. Available from: http://dx.doi.org/10.1007/s10806-005-4493-7.

Bracke, M.B.M., Zonderland, J.J., Lenskens, P., Schouten, W.G.P., Vermeer, H., Spoolder, H.A.M., et al., 2006. Formalised review of environmental enrichment for pigs in relation to political decision making. Appl. Anim. Behav. Sci. 98, 165–182. Available from: http://dx.doi.org/10.1016/j.applanim.2005.08.021.

Brambell, F., 1965. Report of the Technical Committee to Enquire Into the Welfare of Animals Kept Under Intensive Livestock Husbandry Systems. HMSO, London, p. 85.

Brown, S.M., Klaffenböck, M., Nevison, I.M., Lawrence, A.B., 2015. Evidence for litter differences in play behaviour in pre-weaned pigs. Appl. Anim. Behav. Sci. 172, 17–25. Available from: http://dx.doi.org/10.1016/j.applanim.2015.09.007.

Bunter, K.L., Lewis, C.R.G., Newman, S., 2015. Social genetic effects influence reproductive performance of group-housed sows. J. Anim. Sci. 93, 3783–3793.

Burgdorf, J., Panksepp, J., 2006. The neurobiology of positive emotions. Neurosci. Biobehav. Rev. 30, 173–187. Available from: http://dx.doi.org/10.1016/j.neubiorev.2005.06.001.

Burgdorf, J., Colechio, E.M., Stanton, P., Panksepp, J., 2017. Positive emotional learning induces resilience to depression: a role for NMDA receptor-mediated synaptic plasticity. Curr. Neuropharmacol. 15, 3–10. Available from: http://dx.doi.org/10.2174/1570159x14666160422110344.

Calcagnetti, D.J., Schechter, M.D., 1992. Place conditioning reveals the rewarding aspect of social interaction in juvenile rats. Physiol. Behav. 51, 667–672. Available from: http://dx.doi.org/10.1016/0031-9384(92)90101-7.

Camerlink, I., Turner, S.P., 2013. The pig's nose and its role in dominance relationships and harmful behaviour. Appl. Anim. Behav. Sci. 145, 84–91. Available from: http://dx.doi.org/10.1016/j.applanim.2013.02.008.

Camerlink, I., Bijma, P., Kemp, B., Bolhuis, J.E., 2012. Relationship between growth rate and oral manipulation, social nosing, and aggression in finishing pigs. Appl. Anim. Behav. Sci. 142, 11–17. Available from: http://dx.doi.org/10.1016/j.applanim.2012.09.004.

Canario, L., Turner, S.P., Roehe, R., Lundeheim, N., D'eath, D., Lawrence, R.B., et al., 2012. Genetic associations between behavioral traits and direct-social effects of growth rate in pigs. J. Anim. Sci. 90, 4706–4715. Available from: http://dx.doi.org/10.2527/jas2012-5392.

Chalmers, D., 2007. The hard problem of consciousness. The Blackwell Companion to Consciousness. Wiley, Hoboken, NJ, pp. 223–235. Available from: http://dx.doi.org/10.1002/9780470751466.ch18

Chaloupková, H., Illmann, G., Bartoš, L., Špinka, M., 2007. The effect of pre-weaning housing on the play and agonistic behaviour of domestic pigs. Appl. Anim. Behav. Sci. 103, 25–34. Available from: http://dx.doi.org/10.1016/j.applanim.2006.04.020.

Chan, W., Newberry, R.C., 2011. Affective qualities of the bark vocalizations of domestic juvenile pigs. In: Pajor, E., Marchant Forde, J.N. (Eds.), Proc. 45th ISAE, July 31–August 4, Indianapolis, IN. Wageningen Academic Publishers, Wageningen, NL. p. 34, http://www.applied-ethology.org/hres/2011%20International%20Congress%20Proceedings,%20Indianapolis.pdf.

Chan, W.Y., Cloutier, S., Newberry, R.C., 2011. Barking pigs: differences in acoustic morphology predict juvenile responses to alarm calls. Anim. Behav. 82, 767–774. Available from: http://dx.doi.org/10.1016/j.anbehav.2011.07.007.

Christensen, T., Lawrence, A., Lund, M., Stott, A., Sandøe, P., 2012. How can economists help to improve animal welfare? Anim. Welfare 21, 1–10. Available from: http://dx.doi.org/10.7120/096272812X13345905673449.

Cohen, S., Pressman, S.D., 2006. Positive affect and health. Curr. Dir. Psychol. Sci. 15, 122–125. Available from: http://dx.doi.org/10.1111/j.0963-7214.2006.00420.x.

Dawkins, M., 1977. Do hens suffer in battery cages? Environmental preferences and welfare. Anim. Behav. 25, 1034–1046, doi:10.1016/0003-3472(77)90054-9.

Dawkins, M.S., 1983. Battery hens name their price: consumer demand theory and the measurement of ethological "needs". Anim. Behav. 31, 1195–1205, doi:10.1016/S0003-3472(83)80026-8.

Dawkins, M.S., 1990. From an animal's point of view: motivation, fitness and animal welfare. Behav. Brain Sci. 13, 1–61. Available from: http://dx.doi.org/10.1017/S0140525X00077104.

Dawkins, M.S., 2008. The science of animal suffering. Ethology 114, 937–945. Available from: http://dx.doi.org/10.1111/j.1439-0310.2008.01557.x.

Dawkins, M.S., 2012. Why Animals Matter: Animal Consciousness, Animal Welfare, and Human Well-being. Academic Press, Cambridge, MA. Available from: http://dx.doi.org/10.1016/j.anbehav.2012.08.006

Dawkins, M.S., 2017. Animal welfare with and without consciousness. J. Zool. 301, 1–10. Available from: http://dx.doi.org/10.1111/jzo.12434.

D'Eath, R.B., Arnott, G., Turner, S.P., Jensen, T., Lahrmann, H.P., Busch, M.E., et al., 2014. Injurious tail biting in pigs: how can it be controlled in existing systems without tail docking? Animal 8, 1479–1497. Available from: http://dx.doi.org/10.1017/S1751731114001359.

D'Eath, R.B., Jarvis, S., Baxter, E.M., Houdijk, J., 2017. Mitigating hunger in pregnant sows. In: Špinka, M. (Ed.), Advances in Pig Welfare. Woodhead Publishing, Duxford, UK.

Defra, 2003. Code of Recommendations for the Welfare of Livestock: Pigs. Defra Publications, London.

de Jonge, F.H., Boleij, H., Baars, A.M., Dudink, S., Spruijt, B.M., 2008a. Music during playtime: using context conditioning as a tool to improve welfare in piglets. Appl. Anim. Behav. Sci. 115, 138–148. Available from: http://dx.doi.org/10.1016/j.applanim.2008.04.009.

de Jonge, F.H., Tilly, S., Baars, A.M., Spruijt, B.M., 2008b. On the rewarding nature of appetitive feeding behaviour in pigs (Sus scrofa): do domesticated pigs contrafreeload? Appl. Anim. Behav. Sci. 114, 359–372. Available from: http://dx.doi.org/10.1016/j.applanim.2008.03.006.

Denton, D., Shade, R., Zamarippa, F., Egan, G., Blair-West, J., McKinley, M., et al., 1999. Neuroimaging of genesis and satiation of thirst and an interoceptor-driven theory of origins of primary consciousness. Proc. Natl. Acad. Sci. U.S.A. 96, 5304–5309.

Denton, D.A., McKinley, M.J., Farrell, M., Egan, G.F., 2009. The role of primordial emotions in the evolutionary origin of consciousness. Conscious. Cogn. 18, 500–514.

Dixhoorn, I., van, Reimert, I., Middelkoop, J., Bolhuis, E., Wisselink, H., Koerkamp, P., et al., 2016. Enriched housing reduces disease susceptibility to co-infection with porcine reproductive and respiratory virus (PRRSV) and *Actinobacillus pleuropneumoniae* (*A. pleuropneumoniae*) in young pigs. PLoS One. 11, e0161832.

Donaldson, T.M., Newberry, R.C., Špinka, M., Cloutier, S., 2002. Effects of early play experience on play behaviour of piglets after weaning. Appl. Anim. Behav. Sci. 79, 221–231. Available from: http://dx.doi.org/10.1016/S0168-1591(02)00138-7.

Douglas, C., Bateson, M., Walsh, C., Bédué, A., Edwards, S.A., 2012. Environmental enrichment induces optimistic cognitive biases in pigs. Appl. Anim. Behav. Sci. 139, 65–73. Available from: http://dx.doi.org/10.1016/j.applanim.2012.02.018.

Dudink, S., Simonse, H., Marks, I., de Jonge, F.H., Spruijt, B.M., 2006. Announcing the arrival of enrichment increases play behaviour and reduces weaning-stress-induced behaviours of piglets directly after weaning. Appl. Anim. Behav. Sci. 101, 86–101. Available from: http://dx.doi.org/10.1016/j.applanim.2005.12.008.

Edgar, J.L., Mullan, S.M., Pritchard, J.C., McFarlane, U.J.C., Main, D.C.J., 2013. Towards a "good life" for farm animals: development of a resource tier framework to achieve positive welfare for laying hens. Animals 3, 584–605. Available from: http://dx.doi.org/10.3390/ani3030584.

Faucitano, L., Goumon, S., 2017. Transport of pigs to slaughter and associated handling. In: Špinka, M. (Ed.), Advances in Pig Welfare. Woodhead Publishing, Duxford, UK.

FAWC, 2009. Farm Animal Welfare in Great Britain: Past, Present and Future. FAWC, UK, pp. 1–70.

Fowler, J.H., Christakis, N.A., 2008. Dynamic spread of happiness in a large social network: longitudinal analysis over 20 years in the Framingham Heart Study. BMJ Clin. Res. Ed. 337, a2338. Available from: http://dx.doi.org/10.1136/bmj.a2338.

Franks, B., Higgins, E.T., 2012. Effectiveness in humans and other animals: a common basis for well-being and welfare. In: Olson, J.M., Zanna, M.P. (Eds.), Advances in Experimental Social Psychology. Elsevier, Amsterdam, p. 357. Available from: http://dx.doi.org/10.1016/B978-0-12-394281-4.00006-4

Fraser, D., Duncan, I.J., 1998. "Pleasures", 'pains' and animal welfare: toward a natural history of affect. Anim. Welfare. 7, 383–396.

Fraser, D., Weary, D.M., Pajor, E.A., Milligan, B.N., 1997. A scientific conception of animal welfare that reflects ethical concerns. Anim. Welfare 6, 187–205.

Fredrickson, B.L., 2003. The value of positive emotions—the emerging science of positive psychology in coming to understand why it's good to feel good. Am. Sci. 91, 330–335.

Freund, J., Brandmaier, A.M., Lewejohann, L., Kirste, I., Kritzler, M., Kruger, A., et al., 2015. Association between exploratory activity and social individuality in genetically identical mice living in the same enriched environment. Neuroscience 309, 140–152.

Friedman, H.S., Kern, M.L., 2014. Personality, well-being, and health. Annu. Rev. Psychol. 65, 719–742. Available from: http://dx.doi.org/10.1146/annurev-psych-010213-115123.

Garnett, T., Appleby, M.C., Balmford, A., Bateman, I.J., Benton, T.G., Bloomer, P., et al., 2013. Sustainable intensification in agriculture: premises and policies. Sci. Mag. 341, 33–34. Available from: http://dx.doi.org/10.1126/science.1234485.

Goumon, S., Špinka, M., 2015. Emotional contagion of distress in young pigs is potentiated by previous exposure to the same stressor. Anim. Cogn. 19, 501–511.

Hagen, K., Broom, D.M., 2004. Emotional reactions to learning in cattle. Appl. Anim. Behav. Sci. 85, 203–213.

Harding, E.J., Paul, E.S., Mendl, M., 2004. Cognitive bias and affective state. Nature 427, 312. Available from: http://dx.doi.org/10.1038/427312a.

Harrison, R., 1964. Animal Machines: The New Factory Farming Industry. Vincent Stuart, London.

Haskell, M., Wemelsfelder, F., Mendl, M.T., Calvert, S., Lawrence, A.B., 1996. The effect of substrate-enriched and substrate-impoverished housing environments on the diversity of behaviour in pigs. Behaviour. 133, 741–761.

Held, S.D.E., Špinka, M., 2011. Animal play and animal welfare. Anim. Behav. 81, 891–899. Available from: http://dx.doi.org/10.1016/j.anbehav.2011.01.007.

Held, S., Mendl, M., Devereux, C., Byrne, R.W., 2001. Studies in social cognition: from primates to pigs. Anim. Welfare 10, S209−S217.

Herskin, M.S., Di Giminiani, P., 2017. Pain in pigs: characterisation, mechanisms and indicators. In: Špinka, M. (Ed.), Advances in Pig Welfare. Woodhead Publishing, Duxford, UK.

Higgins, E.T., 2011. Beyond pleasure and pain: How motivation works. Oxford University Press.

Hughes, B.O., Duncan, I.J.H., 1988. The notion of 'ethological need', models of motivation and animal welfare. Anim. Behav. 36, 1696−1707.

Humphreys, A.P., Einon, D.F., 1981. Play as a reinforcer for maze-learning in juvenile rats. Anim. Behav. 29, 259−270. Available from: http://dx.doi.org/10.1016/S0003-3472(81)80173-X.

Jensen, M.B., Studnitz, M., Halekoh, U., Pedersen, L.J., Jørgensen, E., 2008. Pigs' preferences for rooting materials measured in a three-choice maze-test. Appl. Anim. Behav. Sci. 112, 270−283. Available from: http://dx.doi.org/10.1016/j.applanim.2007.07.012.

Kanitz, E., Hameister, T., Tuchscherer, A., Tuchscherer, M., Puppe, B., 2016. Social support modulates stress-related gene expression in various brain regions of piglets. Front. Behav. Neurosci. 10, 1−12. Available from: http://dx.doi.org/10.3389/fnbeh.2016.00227.

Kikusui, T., Winslow, J.T., Mori, Y., 2006. Social buffering: relief from stress and anxiety. Philos. Trans. R. Soc. B: Biol. Sci. 361, 2215−2228. Available from: http://dx.doi.org/10.1098/rstb.2006.1941.

King, J.E., Landau, V.I., 2003. Can chimpanzee (*Pan troglodytes*) happiness be estimated by human raters?. J. Res. Pers. 37, 1−15. Available from: http://dx.doi.org/10.1016/S0092-6566(02)00527-5.

Lagerkvist, C.J., Hess, S., 2011. A meta-analysis of consumer willingness to pay for farm animal welfare. Eur. Rev. Agric. Econ. 38, 55−78. Available from: http://dx.doi.org/10.1093/erae/jbq043.

Lawrence, A.B., 1987. Consumer demand theory and the assessment of animal welfare. Anim. Behav. 35, 293−295.

Leenstra, F., Munnichs, G., Beekman, V., Aramyan, L., Woelders, H., 2011. Killing day-old chicks? Public opinion regarding potential alternatives. Anim. Welfare 20, 37−45.

Lind, N.M., Moustgaard, A., Jelsing, J., Vajta, G., Cumming, P., Hansen, A.K., 2007. The use of pigs in neuroscience: modeling brain disorders. Neurosci. Biobehav. Rev. 31, 728−751. Available from: http://dx.doi.org/10.1016/j.neubiorev.2007.02.003.

Mamouni Limnios, E., Schilizzi, S.G.M., Burton, M., Ong, A., Hynes, N., 2016. Willingness to pay for product ecological footprint: organic vs non-organic consumers. Technol. Forecast. Soc. Change. 111, 338−348. Available from: http://dx.doi.org/10.1016/j.techfore.2016.05.009.

Martin, J.E., Ison, S.H., Baxter, E.M., 2015. The influence of neonatal environment on piglet play behaviour and post-weaning social and cognitive development. Appl. Anim. Behav. Sci. 163, 69−79. Available from: http://dx.doi.org/10.1016/j.applanim.2014.11.022.

Matthews, L.R., Ladewig, J., 1994. Environmental requirements of pigs measured by behavioural demand functions. Anim. Behav. 47, 713−719.

McCulloch, S.P., 2013. A critique of FAWC's five freedoms as a framework for the analysis of animal welfare. J. Agric. Environ. Ethics 26, 959−975. Available from: http://dx.doi.org/10.1007/s10806-012-9434-7.

McGowan, R.T.S., Rehn, T., Norling, Y., Keeling, L.J., 2014. Positive affect and learning: exploring the "eureka effect" in dogs. Anim. Cogn. 17, 577−587.

McMillan, F.D., 2000. Quality of life in animals. Views: forum. JAVMA 216, 1904–1910. Available from: http://dx.doi.org/10.2460/javma.2000.216.1904.

Mellor, D., 2015a. Positive animal welfare states and encouraging environment-focused and animal-to-animal interactive behaviours. N. Z. Vet. J. 63, 9–16. Available from: http://dx.doi.org/10.1080/00480169.2014.926800.

Mellor, D., 2015b. Enhancing animal welfare by creating opportunities for positive affective engagement. N. Z. Vet. J. 63 (1), 3–8. Available from: http://dx.doi.org/10.1080/00480169.2014.926799.

Mellor, D., 2016a. Moving beyond the "Five Freedoms" by updating the "Five Provisions" and introducing aligned "Animal Welfare Aims". Animals 6, 59. Available from: http://dx.doi.org/10.3390/ani6100059.

Mellor, D., 2016b. Updating animal welfare thinking: moving beyond the "Five Freedoms" towards "A Life Worth Living". Animals. 6, 59. Available from: http://dx.doi.org/10.3390/ani6100059.

Mendl, M., Burman, O.H.P., Parker, R.M.A., Paul, E.S., 2009. Cognitive bias as an indicator of animal emotion and welfare: emerging evidence and underlying mechanisms. Appl. Anim. Behav. Sci. 118, 161–181. Available from: http://dx.doi.org/10.1016/j.applanim.2009.02.023.

Mendl, M., Burman, O.H.P., Paul, E.S., 2010. An integrative and functional framework for the study of animal emotion and mood. Proc. Biol. Sci. 277, 2895–2904. Available from: http://dx.doi.org/10.1098/rspb.2010.0303.

Mendl, M., Paul, E., 2004. Consciousness, emotion and animal welfare: insights from cognitive science. Anim. Welfare. 13, S17–S25.

Miele, M., Viessier, I., Evans, A.B., Botreau, R., 2011. Animal welfare: establishing a dialogue between science and society. Anim. Welfare 20, 103–117.

Moran, D., Lucas, A., Barnes, A., 2013. Mitigation win–win. Nat. Climate Change. 3, 611–613. Available from: http://dx.doi.org/10.1038/nclimate1922.

Moran, D., McVittie, A., 2008. Estimation of the value the public places on regulations to improve broiler welfare. Anim. Welfare 17, 43–52.

Mullan, S., Edwards, S.A., Butterworth, A., Whay, H.R., Main, D.C.J., 2011. A pilot investigation of possible positive system descriptors in finishing pigs. Anim. Welfare 20, 439–449.

Musschenga, A.W., 1997. The relation between concepts of quality-of-life, health and happiness. J. Med. Philos. 22, 11–28. Available from: http://dx.doi.org/10.1093/jmp/22.1.11.

Myers, B.D.G., Diener, E., 2012. Who is happy? Psychol. Sci. 6, 10–19. Available from: http://dx.doi.org/10.1111/j.1467-9280.1995.tb00298.x.

Newberry, R.C., Wood-Gush, D.G.M., 1986. Social relationships of piglets in a semi-natural environment. Anim. Behav. 34, 1311–1318. Available from: http://dx.doi.org/10.1016/S0003-3472(86)80202-0.

Newberry, R.C., Wood-Gush, D.G.M., 1988. Development of some behaviour patterns in piglets under semi-natural conditions. Anim. Prod. 46, 103–109. Available from: http://dx.doi.org/10.1017/S0003356100003160.

Newberry, R.C., Wood-Gush, D.G.M., Hall, J.W., 1988. Playful behaviour of piglets. Behav. Process. 17, 205–216. Available from: http://dx.doi.org/10.1016/0376-6357(88)90004-6.

Ocepek, M., Newberry, R.C., Andersen, I.L., 2017. Trade-offs between litter size and offspring fitness in domestic pigs subjected to different genetic selection pressures. Appl. Anim. Behav. Sci. 193, 7–14. Available from: http://dx.doi.org/10.1016/j.applanim.2017.03.008.

OECD, FAO, 2016. OECD-FAO Agricultural Outlook 2016–2025. Special Focus: Sub-Saharan Africa.

Panksepp, J., 2011. Neuroscience and biobehavioral reviews: the basic emotional circuits of mammalian brains: do animals have affective lives? Neurosci. Biobehav. Rev. 35, 1791–1804. Available from: http://dx.doi.org/10.1016/j.neubiorev.2011.08.003.

Panksepp, J., Zellner, M.R., 2004. Towards a neurobiologically based unified theory of aggression. Rev. Int. Psychol. Soc. 17, 37–61.

Panksepp, J., Lane, R.D., Solms, M., Smith, R., 2017. Reconciling cognitive and affective neuroscience perspectives on the brain basis of emotional experience. Neurosci. Biobehav. Rev. 76, 187–215.

Parker, M.O., O'Connor, E.A., McLeman, M.A., Demmers, T.G.M., Lowe, J.C., Owen, R.C., et al., 2010. The impact of chronic environmental stressors on growing pigs, *Sus scrofa* (Part 2): social behaviour. Animal. 4, 1910–1921. Available from: http://dx.doi.org/10.1017/S1751731110001084.

Pedersen, L.J., Jensen, M.B., 2007. Concurrent schedules of reinforcement as a method to quantify the relative attractiveness of two rooting materials. Appl. Anim. Behav. Sci. 107, 147–151. Available from: http://dx.doi.org/10.1016/j.applanim.2006.07.007.

Pedersen, L.J., Herskin, M.S., Forkman, B., Halekoh, U., Kristensen, K.M., Jensen, M.B., 2014. How much is enough? The amount of straw necessary to satisfy pigs' need to perform exploratory behaviour. Appl. Anim. Behav. Sci. 160, 46–55. Available from: http://dx.doi.org/10.1016/j.applanim.2014.08.008.

Pellis, S.M., Pellis, V.C., 2016. Play fighting in Visayan warty pigs (*Sus cebifrons*): insights on restraint and reciprocity in the maintenance of play. Behaviour 153, 727–747. Available from: http://dx.doi.org/10.1163/1568539X-00003346.

Petrů, M., Špinka, M., Lhota, S., Šípek, P., 2008. Head rotations in the play of Hanuman langurs (Semnopithecus entellus): description and analysis of function. J. Comp. Psychol. 122, 9–18. Available from: http://dx.doi.org/10.1037/0735-7036.122.1.9.

Phillips, C., 2008. Animal welfare: a construct of positive and negative affect? Vet. J. 175, 291–292. Available from: http://dx.doi.org/10.1016/j.tvjl.2007.05.015.

Rault, J.L., 2012. Friends with benefits: social support and its relevance for farm animal welfare. Appl. Anim. Behav. Sci. 136, 1–14. Available from: http://dx.doi.org/10.1016/j.applanim.2011.10.002.

Rault, J.L., 2016. Effects of positive and negative human contacts and intranasal oxytocin on cerebrospinal fluid oxytocin. Psychoneuroendocrinology 69, 60–66. Available from: http://dx.doi.org/10.1016/j.psyneuen.2016.03.015.

Rauw, W.M., 2013. A note on the consistency of a behavioral play marker in piglets. J. Anim. Sci. Biotechnol. 4, 33. Available from: http://dx.doi.org/10.1186/2049-1891-4-33.

Reimert, I., Bolhuis, J.E., Kemp, B., Rodenburg, T.B., 2013. Indicators of positive and negative emotions and emotional contagion in pigs. Physiol. Behav. 109, 42–50. Available from: http://dx.doi.org/10.1016/j.physbeh.2012.11.002.

Reimert, I., Bolhuis, J.E., Kemp, B., Rodenburg, T.B., 2014. Social support in pigs with different coping styles. Physiol. Behav. 129, 221–229. Available from: http://dx.doi.org/10.1016/j.physbeh.2014.02.059.

Reimert, I., Bolhuis, J.E., Kemp, B., Rodenburg, T.B., 2015. Emotions on the loose: emotional contagion and the role of oxytocin in pigs. Anim. Cogn. 18, 517–532. Available from: http://dx.doi.org/10.1007/s10071-014-0820-6.

Reimert, I., Fong, S., Rodenburg, T.B., Bolhuis, J.E., 2017. Emotional states and emotional contagion in pigs after exposure to a positive and negative treatment. Appl. Anim. Behav. Sci. 193, 37–42. Available from: http://dx.doi.org/10.1016/j.applanim.2017.03.009.

Renner, M.J., 1988. Learning during exploration: the role of behavioral topography during exploration in determining subsequent adaptive behavior in the Sprague–Dawley rat (*Rattus norvegicus*). Int. J. Comp. Psychol. 2, 43–56.

Rutherford, K.M.D., Donald, R.D., Lawrence, A.B., Wemelsfelder, F., 2012. Qualitative behavioural assessment of emotionality in pigs. Appl. Anim. Behav. Sci. 139, 218–224. Available from: http://dx.doi.org/10.1016/j.applanim.2012.04.004.

Rutherford, K.M.D., Baxter, E.M., D'Eath, R.B., Turner, S.P., Arnott, G., Roehe, R., et al., 2013. The welfare implications of large litter size in the domestic pig I: biological factors. Anim. Welfare. 22, 199–218. Available from: http://dx.doi.org/10.7120/09627286.22.2.199.

Scorsolini-Comin, F., Fontaine, A.M.G.V., Koller, S.H., Santos, M.A., 2009. From authentic happiness to well-being: the flourishing of positive psychology. Dos. Psicol. Reflex. Crit. 26, 663–670. Available from: http://dx.doi.org/10.1590/S0102-79722013000400006.

Seligman, M.E.P., Csikszentmihalyi, M., 2000. Positive psychology—an introduction. Am. Psychol. 55, 5–14.

Seligman, M.E.P., Steen, T.A., Park, N., Peterson, C., 2005. Positive psychology progress: empirical validation of interventions. Am. Psychol. 60, 410–421. Available from: http://dx.doi.org/10.1037/0003-066X.60.5.410.

Šilerová, J., Špinka, M., Šárová, R., Algers, B., 2010. Playing and fighting by piglets around weaning on farms, employing individual or group housing of lactating sows. Appl. Anim. Behav. Sci. 124, 83–89. Available from: http://dx.doi.org/10.1016/j.applanim.2010.02.003.

Špinka, M., 2006. How important is natural behaviour in animal farming systems? Appl. Anim. Behav. Sci. 100, 117–128. Available from: http://dx.doi.org/10.1016/j.applanim.2006.04.006.

Špinka, M., 2012. Social dimension of emotions and its implication for animal welfare. Appl. Anim. Behav. Sci. 138, 170–181. Available from: http://dx.doi.org/10.1016/j.applanim.2012.02.005.

Špinka, M., Wemelsfelder, F., 2011. Environmental challenge and animal agency. In: Appleby, M.C., Mench, J., Olsson, A., Hughes, B.O. (Eds.), Animal Welfare. CABI International, Wallingford, pp. 27–43.

Špinka, M., Newberry, R.C., Bekoff, M., 2001. Mammalian play: training for the unexpected. Q. Rev. Biol. 76, 141–168. Available from: http://dx.doi.org/10.1086/393866.

Stolba, A., Wood-Gush, D.G., 1984. The identification of behavioural key features and their incorporation into a housing design for pigs. Ann. Rech. Vet. 15, 287–299.

Stolba, A., Wood-Gush, D.G.G.M., 1989. The behaviour of pigs in a semi-natural environment. Anim. Prod. 48, 419–425. Available from: http://dx.doi.org/10.1017/S0003356100040411.

Stankowich, T., Blumstein, D.T., 2005. Fear in animals: a meta-analysis and review of risk assessment. Proc. R. Soc. B-Biol. Sci. 272, 2627–2634.

Šustr, P., Špinka, M., Cloutier, S., Newberry, R.C., 2001. Computer-aided method for calculating animal configurations during social interactions from two-dimensional coordinates of color-marked body parts. Behav. Res. Methods Instrum. Comput. 33, 364–370. Available from: http://dx.doi.org/10.3758/BF03195390.

Tallet, C., Brajon, C., Devillers, N., Lensink, J., 2017. Pig–human interactions: creating a positive perception of humans to ensure pig welfare. In: Špinka, M. (Ed.), Advances in Pig Welfare. Woodhead Publishing, Duxford, UK.

Temple, D., Dalmau, A., Ruiz de la Torre, J.L., Manteca, X., Velarde, A., 2011. Application of the Welfare Quality protocol to assess growing pigs kept under intensive conditions in Spain. J. Vet. Behav. Clin. Appl. Res. 6, 138–149. Available from: http://dx.doi.org/10.1016/j.jveb.2010.10.003.

Trimmer, P.C., Houston, A.I., Marshall, J.A.R., Bogacz, R., Paul, E.S., Mendl, M.T., et al., 2008. Mammalian choices: combining fast-but-inaccurate and slow-but-accurate decision-making systems. Proc. R. Soc. B-Biol. Sci. 275, 2353–2361.

Valros, A., 2017. Tail biting. In: Špinka, M. (Ed.), Advances in Pig Welfare. Woodhead Publishing, Duxford, UK.

Verdon, M., Rault, J.L., 2017. Aggression in group housed sows and fattening pigs. In: Špinka, M. (Ed.), Advances in Pig Welfare. Woodhead Publishing, Duxford, UK.

Webster, J., 2005. Animal Welfare: Limping Towards Eden. John Wiley & Sons, Hoboken, NJ.

Webster, J., 2016. Animal welfare: freedoms, dominions and "a life worth living". Animals 6, 35.

Welfare Quality Consortium 2009. Welfare Quality assessment protocol for pigs. Netherlands, Lelystad.

Weiss, A., Adams, M.J., King, J.E., 2011. Happy orang-utans live longer lives. Biol. Lett. 7, 872–874. Available from: http://dx.doi.org/10.1098/rsbl.2011.0543.

Wemelsfelder, F., Hunter, E.A., Mendl, M.T., Lawrence, A.B., 2000. The spontaneous qualitative assessment of behavioural expressions in pigs: first explorations of a novel methodology for integrative animal welfare measurement. Appl. Anim. Behav. Sci. 67, 193–215. Available from: http://dx.doi.org/10.1016/S0168-1591(99)00093-3.

Wemelsfelder, F., Hunter, T.E.A., Mendl, M.T., Lawrence, A.B., 2001. Assessing the "whole animal": a free choice profiling approach. Anim. Behav. 62, 209–220. Available from: http://dx.doi.org/10.1006/anbe.2001.1741.

Wemelsfelder, F., Hunter, A.E., Paul, E.S., Lawrence, A.B., 2012. Assessing pig body language: agreement and consistency between pig farmers, veterinarians, and animal activists. J. Anim. Sci. 90, 3652–3665.

Wood-Gush, D.G.M., Vestergaard, K., 1991. The seeking of novelty and its relation to play. Anim. Behav. 42, 599–606. Available from: http://dx.doi.org/10.1016/S0003-3472(05)80243-X.

Woods, A., 2012. From cruelty to welfare: the emergence of farm animal welfare in Britain, 1964-71. Endeavour 36, 14–22. Available from: http://dx.doi.org/10.1016/j.endeavour.2011.10.003.

World Organisation for Animal Health (OIE), 2016. Article 7.1.5. Guiding principles for the use of animal-based measures (proposed revision, 2016). In: Annex 10, Report of the Fifteenth Meeting of the OIE Animal Welfare Working Group/May 2016, Paris, France. p. 65. Available from: https://www.oie.int/fileadmin/Home/eng/Animal_Welfare/docs/pdf/AWWG_Reports/A_Report_AWWG_2016.pdf.

Yeates, J.W., Main, D.C.J., 2008. Assessment of positive welfare: a review. Vet. J. 175, 293–300. Available from: http://dx.doi.org/10.1016/j.tvjl.2007.05.009.

Young, R.J., Lawrence, A.B., 2003. Do domestic pigs in controlled environments contrafreeload? J. Appl. Anim. Welfare Sci. 6, 309–318.

Young, R.J., Carruthers, J., Lawrence, A.B., 1994. The effect of a foraging device (The "Edinburgh Foodball") on the behaviour of pigs. Appl. Anim. Behav. Sci. 39 (3–4), 237–247. Available from: http://dx.doi.org/10.1016/0168-1591(94)90159-7.

Zonderland, J.J., Wolthuis-Fillerup, M., van Reenen, C.G., Bracke, M.B.M., Kemp, B., Hartog, L.A., et al., 2008. Prevention and treatment of tail biting in weaned piglets. Appl. Anim. Behav. Sci. 110, 269–281. Available from: http://dx.doi.org/10.1016/j.applanim.2007.04.005.

Breeding for pig welfare: Opportunities and challenges

14

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14.1 Introduction

Animal welfare affects efficiency and productivity and therefore forms an important component of sustainability (Keeling, 2005; Broom, 2010). As an example, 20% of piglets are stillborn or die within the neonatal period (see Baxter and Edwards, Chapter 3: Piglet mortality and morbidity: inevitable or unacceptable? for data from several major pig producing countries). The cause of death in those born alive is varied and often multifactorial (e.g., hypothermia, starvation, crushing or savaging by the mother), but in most cases is likely to involve suffering. Neonatal mortality directly compromises all pillars of sustainability; economic (through increased costs of production), environmental (through wastage of feed and energy) and social (through compromised welfare). Within existing production systems there is therefore considerable scope to simultaneously benefit animal welfare and the economic and environmental sustainability of pig production. Increasing global demand for pigmeat produced with ever greater efficiency makes it unlikely that the pressure for economically efficient production practices will diminish. This continuing drive for economic efficiency brings with it a risk that animal welfare is afforded only secondary importance, but also increases the incentive for improving welfare as a means to improve efficiency.

Selective breeding leads to permanent and cumulative change that accrues from one generation to the next. The global pig breeding industry has had major success in improving pig productivity. For example, the annual improvement in growth rate is around 5 g/pig/day (Hermesch et al., 2015). Although this may seem small, when accrued over the entire growing-finishing period and over decades of selection, the improvement in growth has been dramatic. Selective breeding will be crucial in meeting global challenges of ensuring food security and environmental and economic sustainability.

Pigs vary greatly in their expression of negative welfare outcomes even when of the same breed, managed by the same staff and housed on the same farm (e.g., in aggressive behaviour; Figs. 14.1 and 14.2). As this chapter will demonstrate, traits that have a major impact on welfare have been found to be under genetic (as well as non-genetic) control, usually as a result of the interplay of many genes (Balaban et al., 1996). It is commonly the case that genes have pleiotropic effects, meaning that one gene can influence several phenotypic traits that may appear to be unrelated

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Figure 14.1 Example of aggressive behaviour responsible for the lesions shown in Fig. 14.2. *Source*: Photo credit: Marianne Farish, SRUC.

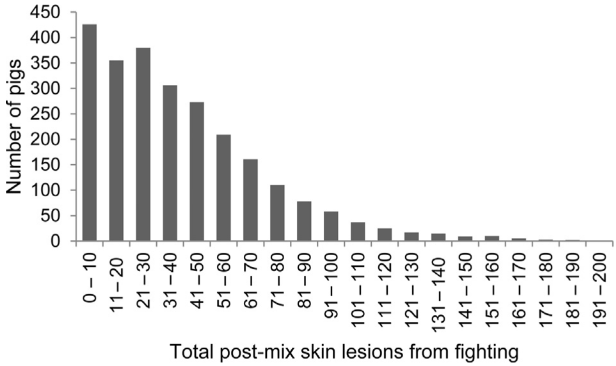

Figure 14.2 Variation in the number of skin injuries received by pigs of the same breed and age and managed on the same farm when recorded 24 h after mixing into a new social group.

(Jensen, 2010). Two genes with different effects (e.g., one affecting a production trait and one affecting a welfare trait) can also be inherited together if located in close proximity on the chromosome. This reduces the likelihood that they are separated onto different chromatids during recombination. Evidence that welfare traits are partially genetically determined by large numbers of genes with pleiotropic effects or in linkage with other genes has two major implications. First, breeding for a production trait (e.g., growth rate) has the potential to lead to desirable or undesirable genetic change in other traits of welfare significance. Second, placing selection pressure on welfare traits themselves ought, if appropriately targeted, to benefit welfare in addition to efforts to improve management practices (for example in the case of neonatal mortality, by providing an appropriate farrowing environment).

This chapter will firstly consider how past selection for productivity has affected welfare. It will then present three examples of the state of the art in selective breeding for welfare traits in their own right. Selection for complex welfare-relevant traits poses practical, economic and ethical challenges which will be discussed before the chapter concludes with a look to the future and the role that current and future innovations may play in overcoming barriers to selection.

14.2 Genetic interactions between production and welfare traits

Pig breeding is geared towards meeting a market demand. That demand dictates that breeding boars should be fertile and sows should be prolific breeders. It also requires that their progeny should grow rapidly to market weight with a maximum proportion of lean meat in the carcass. Specific market needs differ and selection pressure may also be placed on additional traits (e.g., spine and leg conformation and teat number for instance). In general the majority of the selection pressure to date has been placed on litter size, growth rate, feed conversion efficiency and back fat depth in order to achieve large numbers of fast and efficiently growing lean progeny. This has undoubtedly been a highly successful strategy and greatly increased the weight of lean meat produced per sow per year. For example, the United Kingdom has seen a 21% improvement in the weight of pigmeat produced per sow per year (to 1917 kg) over only a 5 year period to 2014 (AHDB, 2015). The correlated consequences for welfare traits have not been so welcome. This is a story repeated across each of the main livestock species (see the review by Rauw et al., 1998 for examples). In one example, selection for leanness in pigs increased the likelihood of homozygosity at the ryanodine receptor locus, increasing the risk of sudden death in response to stressful events (Mohrmann et al., 2006; Cherel et al., 2011). This sudden death, or ‘malignant hyperthermia’ syndrome is controlled by a major gene effect whereby a single locus in the genome has a major impact on trait expression and effective screening of selection candidates has now brought this problem under control. Other welfare traits are likely to have a more complex relationship with selected production traits due to the input of many genes. Selection for large litter size at birth has reduced piglet birth weight which is a major risk factor for piglet mortality (Roehe and Kalm, 2000; Baxter et al., 2008; Rutherford et al., 2013). This has required balancing by selection on birth weight but also survival over the critical neonatal period to slow or halt the increase in mortality. There is also evidence that selection for fast and efficient growth may have had a correlated genetic impact leading to greater aggressiveness of pigs towards pen mates (Desire et al., 2015) and a greater tendency to tail bite (Breuer et al., 2005).

The international dairy breeding industry has faced similar but more pronounced undesirable correlated outcomes of selecting for production traits. Deteriorations in lameness and mastitis resistance and in fertility have led to the broadening of breeding goals such that most national dairy indexes now place at least some pressure on welfare or functional traits in addition to production traits. In the United Kingdom, the Profitable Lifetime Index now places more pressure on these nonproduction traits than conventional production traits (for a description of the selection pressure placed on individual traits see https://dairy.ahdb.org.uk/technical-information/breeding-genetics/%C2%A3pli/). Ultimately the pig breeding industry may follow the lead of the dairy sector by broadening breeding goals either to meet a direct societal demand for higher-welfare standards or to balance the effect of selection for production traits. The next section considers three traits of major welfare significance and discusses the feasibility of breeding for improvements in these traits.

14.3 State of the art in breeding for improved pig welfare

The amelioration of welfare problems via breeding has the advantage that traits can be improved without the requirement for major structural or management changes on the farm itself and are therefore relatively inexpensive solutions to implement. Some complex welfare problems in intensive production systems, such as tail biting and aggression, have existed for decades, have significant negative impacts on economic and environmental sustainability but have known management solutions that are too costly for many producers to implement. Whilst continued effort is required to find affordable management solutions to these problems, research effort in recent years has also explored the genetic architecture of these traits and their suitability for improvement through selection.

Here we illustrate the state of knowledge regarding the feasibility and probable consequences of breeding for improvements in complex welfare traits by taking three examples. The examples discussed are of welfare issues that have persisted for many decades and are tolerated as routine within current production systems but that have the potential for improvement via selection. These examples present ethical dilemmas, each to a different extent, with regard to the acceptability of using selection to improve welfare.

14.3.1 Neonatal survival

Little progress has been made over the last two decades in reducing piglet mortality and it remains high at close to 20% including still-births. Piglet mortality is multifaceted in nature and, as a result, finding solutions requires addressing all aspects of the problem. The subject is discussed in depth by Baxter and Edwards (Chapter 3: Piglet mortality and morbidity: inevitable or unacceptable?) where the results of selection for large litter size are quantified. That chapter illustrates the success achieved in increasing the number of piglets born alive through selective breeding, but also illustrates the close positive correlation with a heightened pre-weaning mortality rate. Baxter and Edwards also provide a detailed description of the many genetic and management interventions that can be made to improve piglet survival. Here the use of genetic selection as one method to improve piglet survival will briefly be summarised. Historically breeding programmes have focused on improving total number of piglets born, however the focus on such traits has led to a concomitant increase in piglet mortality (Rutherford et al., 2013). Adjusting selection criteria to include neonatal survival, in addition to number born, is a more sustainable strategy and one that has achieved success in improving piglet survival rates (Roehe et al., 2009, 2010). The Danish pig industry, renowned for its success in increasing litter size, has recognised the accompanying significant increase in mortality which occurred (5% increase in total pre-weaning mortality). In 2004 it changed its selection criterion from 'total born' to 'live piglets at day 5' (Su et al., 2007) and, although mortality remains high, it has been stabilised with the net result of an increase of 2.3 pigs weaned/litter. An additional important breeding goal to improve piglet survival involves reducing intra-litter birth weight variability (e.g., Rydhmer, 2000; Damgaard et al., 2003; Canario et al., 2010; Kapell et al., 2011). The presence of giants and runts in a litter increases competition at the udder for milk and often results in the weakest members of the litter dying. The use of canalised selection programmes to stabilise birth weight variation has been successful in other litter-bearing mammals, such as the rabbit (Garreau et al., 2008). Selecting for improved placental efficiency (van Rens et al., 2005) and investigating strategies for breeding a more robust piglet (Knap, 2005) are other options to tackle the issue of piglet mortality. Finally a major contributing factor in the fate of the piglet is the behaviour of the mother. Breeding for improved maternal behaviour is therefore an important part of any breeding strategy to augment piglet survival (Grandison et al., 2005; Baxter et al., 2011).

14.3.2 Aggressiveness towards pen mates

Most commercially farmed pigs are regrouped into new social groups several times in their life in order to house animals together of similar weight and to ensure available buildings are fully occupied. This dynamic social environment in which pigs are suddenly introduced to others of similar competitive ability in an area from which they cannot escape contrasts with that in the wild where integration of unfamiliar pigs is less common and more gradual (Mauget, 1981). Fighting to establish new dominance relationships can be intense under commercial production and can lead to many skin lesions (Turner et al., 2006). The quality of behaviour performed is similar to that between wild boar, but the quantity of aggression is typically greatly increased in commercial production (Mendl, 1995; Verdon and Raoult, Chapter 8: Aggression in group housed sows and fattening pigs). Low-cost, labour efficient methods to reduce aggression, such as grouping animals in the dark or using scent masking chemicals, have minimal benefits (Arey and Edwards, 1998) and the avoidance of regrouping is not economically feasible for many producers. Mixing-induced aggression causes activation of the hypothalamic–pituitary–adrenal axis, indicative of a physiological stress response (Fernandez et al., 1994) and the resultant skin lesions increase the risk of infection. A greater portion of the dietary energy intake is expended on activity and food conversion efficiency is reduced (Rundgren and Löfquist, 1989; Tan et al., 1991).

Pigs of the same breed produced by the same company differ greatly in their aggressiveness (Fig. 14.2). A positively skewed distribution whereby a minority of pigs engage in very high levels of aggression has been found in all populations studied, each from different breeding organisations (e.g., Turner et al., 2009; Desire et al., 2015). Heritability (possible range from 0 to 1) quantifies the amount of variation in a phenotypic trait that is due to additive genetic variation between individuals. Some aggressive behavioural traits have heritabilities as high as that of growth rate (e.g., duration of reciprocal fighting; heritability 0.43 SE 0.04; Turner et al., 2009). The number and location of skin injuries has been shown to be predictive at the genetic level of the severity and type (reciprocated or non-reciprocated) of aggression that a pig has engaged in. For example, the genetic correlation between the duration of reciprocated fighting a pig has been involved with and the count of lesions to the front third of the body is 0.67 SE 0.04 (Turner et al., 2009). Recording of skin lesion number and location can therefore provide a rapid estimation of the genetic propensity of pigs to engage in damaging aggression. Careful choice of which aggressiveness trait to improve is important. Skin lesions are received to different parts of the body as a result of different forms of aggression and at different times relative to regrouping. Selection against most of these lesion traits will reduce the amount of active aggression a pig engages in, but will lead to a correlated reduction in the genetic propensity of the pigs to grow rapidly and efficiently (Desire et al., 2015). Fortunately, there appears to be no such correlation between productivity and the number of lesions a pig receives to the front portion of the body immediately after regrouping when the level of injury is most severe.

However, recording lesion numbers for all selection candidates remains a barrier to implementation and the ethical justification must be strong in order to breed against a naturally-occurring behaviour. To inform this ethical debate, it is necessary to understand how selection to reduce aggressiveness may affect other behavioural traits. To date there is no evidence that less aggressive pigs are genetically more lethargic although they appear to be more unwilling to be separated from pen mates and moved into a weigh crate (D'Eath et al., 2009). To understand more fully how reducing aggressiveness may benefit welfare, it is important to probe the affective state of the animals as an indicator of their emotions. Critically it is necessary to confirm that unaggressive pigs do not simply avoid fights due to heightened fearfulness of other pigs. Current effort is addressing this knowledge gap and may inform the merit of selecting against aggressiveness.

14.3.3 Tail biting

Chewing of tails by pen mates is a major animal welfare and economic problem resulting in pain, infection, reduced weight gain and carcass trimming or condemnation (Kritas and Morrison, 2007; Sinisalo et al., 2012; Munsterhjelm et al., 2013). Multifactorial causation and two or possibly three aetiologies (Taylor et al., 2010 and reviewed by D'Eath et al., 2014) make it particularly challenging to prevent tail biting. The most successful strategy of providing edible, deformable and destructible material such as plentiful straw is not compatible with the slurry systems on many farms. Tail docking (amputation of a portion of the tail in early life) is itself a welfare challenge and reduces but does not eliminate the risk of tail biting. Tail docking continues to be used for 95% or more of pigs in Germany, Denmark, Belgium, France, Ireland, The Netherlands and Spain, and for over 80% in the United Kingdom (EFSA, 2007; Harley et al., 2012). An abolition of tail docking has already been implemented in some European countries (e.g., Finland, Norway, Sweden, Switzerland) and in other countries the pig industry has made a commitment to move away from routine tail docking. The high welfare and economic consequences of tail biting together with the increasing constraints over the use of tail docking require that an effective solution to tail biting is identified that is compatible with current production systems.

Chapter 5: Tail biting in this book by Valros describes in detail the evidence for breed differences and within-breed genetic variation in tail biting behaviour. Here we briefly summarise this evidence and consider whether it may point towards a breeding solution to this long-standing problem. The tendency to tail bite appears to be lowly heritable and only in some lines (heritability in Landrace pigs of 0.05 ± 0.02; Breuer et al., 2005). In reality the estimation of an accurate heritability is problematic as the behaviour is episodic, the identification of the biters is highly labour intensive, biters form a minority of the population requiring large sample sizes and the trait is often recorded on a binary scale (biter or not). This poses a daunting barrier to routine phenotyping for the purposes of selection. It also means that without these barriers the heritability may be much higher than that reported by Breuer et al. (2005) meaning that the potential for genetic change has probably been underestimated.

The use of molecular genetic markers that explain a significant part of the variance in expression of a trait can help to overcome the need for routine phenotyping. Screening of selection candidates for their genotype at these marker regions can be performed in early life. In the case of tail biting, there is evidence that single nucleotide polymorphism (SNP) markers differ in biting and victim pigs in contrast to non-biting controls from the same pen (Wilson et al., 2012). Brain gene expression studies also suggest that biters and victims share more in common at this molecular level than unaffected pigs from the same group (Brunberg et al., 2013a) or a different group (Brunberg et al., 2013b). If these genetic differences are validated in other populations, use of molecular genetic information may have a role to play in selecting pigs that avoid the delivery or receipt of tail biting. In reality many markers will each account for a small portion of the total variance in a complex phenotypic trait. Promising alternatives to the use of individual molecular markers exist. Specifically the use of genome-wide selection that does not require routine behavioural phenotyping, or selection on associative genetic effects which avoids the need for behavioural phenotyping altogether, may open the way to selective breeding on traits that are highly complex and costly to phenotype, such as tail biting. Both of these methods are described in Section 14.5.

14.4 Barriers to breeding for pig welfare

Deliberate selection to improve welfare traits, particularly where this involves modifying behaviour, may seem inappropriate to some when management solutions are known and the change may be perceived to reduce the animals' 'naturalness' (D'Eath et al., 2010). A counter argument could be made that this may simply reverse the effects of past selection (e.g., where there is evidence of effects of selection for heightened productivity on aggression and tail biting; Breuer et al., 2005; Desire et al., 2015). Alternatively, it may be viewed that much research effort to find economically feasible management solutions has had only partial success and that ongoing and routine welfare problems should be addressed with every tool available. A reasonable concern is that manipulation of overt behavioural expression as a trait in a breeding goal could have a number of currently unquantified but undesirable impacts on fundamental biological systems or on emotional experiences (e.g., see Mormède et al., 2011 for a review of how selection strategies could alter stress response axes). Alternatively, Sandøe et al. (1999) and D'Eath et al. (2010) have discussed how selection may prevent the expression of behaviours without suppressing the underlying motivation which previously led to its performance. Fully understanding the outcomes of selection, the cognitive processes that underlie these and, by inference, the emotional experiences of the animals is probably essential to secure societal support where the ethical argument for selection is not very evident. This will undoubtedly require that breeding decisions are made on a case by case basis. Where selection is implemented for animals that are better able to thrive in commercial production systems, this must not simply allow management to deteriorate such that the net outcome for the animals remains unchanged.

Significant practical barriers also need to be overcome before implementing selection for any new trait, but particularly one where improving animal welfare is the primary goal. The inclusion of new traits in a multitrait selection index inevitably leads to a reduced response rate in existing traits as less selection pressure can be placed upon them (Falconer and Mackay, 1996). This dilution occurs even if the new trait is not antagonistically correlated with any of the existing traits. Antagonistic genetic correlations, where improving one trait will lead to a genetic deterioration in another, can further constrain the rate of genetic progress in either trait.

As for any trait, there is a need to quantify any genotype × environment interaction effects. These interactions can mean that a selection candidate ranked as most superior based on breeding values predicted in one environment can be re-ranked to a lower level if its genetic merit is calculated using phenotypic data collected from a different environment. One example is where pigs are reared under organic farming conditions as compared to conventional conditions (Wallenbeck et al., 2009). It is important to minimise the impact of genotype × environment interactions on the realisation of genetic potential on normal commercial farms. Partly this is achieved by ensuring that nucleus farms, where the highest genetic merit animals are housed, have physical environments that are as representative of commercial farms as possible whilst allowing for enhanced data collection. Nucleus farms do, however, have strict biosecurity regulations to minimise the risk of diseases entering the herd. Breeding organisations use contract farms where they test the relatives of nucleus animals under practical conditions and then use the performance of these relatives to select nucleus animals based on their genetic relationships. The expression of behavioural traits is greatly influenced by the environment (Baxter et al., 2011) and robustly quantifying genotype × environment interactions becomes particularly important for such traits. This necessitates potentially timeconsuming recording in multiple environments to quantify these interactions and to account for their effects in selection decisions.

The selection pressure that breeders choose to place upon a trait is usually determined by the economic value gained from its improvement (Wall et al., 2010). Pig breeding relies upon an index of selected traits that are each weighted based upon their economic benefit and correlations with other traits in the index. Welfare traits have both a market value (quantifying their effects on profitability) and a non-market value (recognising their social or ethical value; Kanis et al., 2005). Even gaining a true estimate of the market value of a trait is difficult as data are lacking with which to adequately quantify the full economic benefit of their improvement (e.g., the labour cost saved by avoiding the need to respond to tail biting episodes; D'Eath et al., 2016). Estimating the animal welfare or societal benefit of improving a welfare trait is more challenging still and no mechanisms exist to pay breeders or farmers for the non-market value of their breeding choices. Some consumers may be willing to pay for higher-welfare products and there may be a role for approaches such as contingent valuation that measures a consumer's willingness to pay for non-market traits (Lawrence et al., 2004). In practice, desired gains methodology has been used to improve traits whose total value is difficult to estimate. This method specifies the improvement to be made in a trait without reference to its economic weight and for some of the traits discussed above may be an appropriate approach.

Traits currently included in selection indexes can be rapidly and accurately measured on large numbers of animals. Phenotyping complex traits, particularly those involving unpredictable social interactions, requires the development of rapid and accurate indicator traits that are genetically correlated to the real trait of interest. Identifying and refining these indicator traits is no small task. For example, with regard to tail biting tendency, subtle behavioural changes may be indicative of the imminent onset of an outbreak (e.g., tails held in a downwards position; Statham et al., 2009; Zonderland et al., 2009) but tests to reliably and rapidly quantify an individual's propensity to actually perform tail biting have yet to be developed for use in a commercial context. There has been a recent proliferation of sensors and algorithms at various stages of validation for automatically detecting welfare outcomes in pigs and other species (e.g., Viazzi et al., 2014; Gronskyte et al., 2016; Nasirahmadi et al., 2016). These 'smart farming' technologies, developed primarily to aid on-farm management, may, with adequate validation, be used to phenotype welfare traits for use in breeding programmes that would otherwise require considerable human labour input. In addition to the advances in farm technology, changes in breeding methodology will open the door to selection on traits that have so far proved too difficult or costly to measure. Two of the most promising methods for improving welfare traits that are difficult to measure are considered below.

14.5 The role of modern breeding tools in overcoming barriers to selection

14.5.1 Genome-wide selection

Genome-wide selection can simultaneously exploit information on the small effects of many different genomic regions that, individually, make a contribution to total trait genetic variation that is too small to efficiently be used in selection on their own. However, the accumulation of all of the minor contributions of many SNPs that are densely distributed across the whole genome into a direct genomic value allows efficient selection. The direct genomic value is complementary to a conventional estimated breeding value derived through routine phenotyping and pedigree information (Berry et al., 2011). Genome-wide selection relies upon two populations. In the first ('reference population') phenotyping is performed to confirm the SNPs that contribute to the genetic variation in the trait. Genotyping of pigs in a subsequent larger population of selection candidates can then determine the genetic propensity towards a particular trait at a young age and without the need for phenotyping. Routine behavioural phenotyping only in the reference population therefore substantially reduces the cost of this approach. Furthermore, the rate of genetic change can be greatly accelerated by the use of genomic information by reducing the generation interval (Goddard, 2009). This approach does, however, require periodic reassessment of whether the genotypic changes are continuing to lead to the desired phenotypic changes in later generations. The cost of high density genotyping of animals is falling and many elite selection candidates are now routinely genotyped by pig breeding organisations. Armed with genotypic information, any trait can be placed under selection once the association between SNPs and phenotypic expression has been quantified in a relevant reference population.

14.5.2 Selection on associative genetic effects

Selection on associative genetic effects, also termed social or indirect genetic effects, targets social interactions between group housed animals rather than a single behavioural trait. Whereas direct genetic selection targets a trait related to the individual's own genetic propensity, associative breeding selects animals for their heritable effect on the productivity of their group members (Griffing, 1967; Muir, 2005; Bijma et al., 2007). For example, a pig may negatively impact the growth rate of its pen mates through its behaviour, such as tail biting or aggression, although it is also possible for an individual to have a heritable effect on its group members by its tendency (or not) to transmit disease (Ellen et al., 2014).

Associative genetic effects capture this behavioural effect of a pig on the growth of other group members, irrespective of the behavioural trait(s) that causes the effect. It thus addresses social interactions between animals, and may influence any of the behaviours in the repertoire that affect group members rather than a priori targeting a single behaviour. Because estimates are based on production traits, such as growth rate in pigs (Bergsma et al., 2008), there is no need for behavioural phenotyping. The method is therefore very promising for improving welfare and productivity simultaneously, whilst capturing the whole behavioural profile. Genetic parameter estimates have been published for several livestock species (Bijma, 2010) and empirical studies have been conducted, including in pigs. A large scale selection experiment in which pigs were selected for either positive or negative associative genetic effects indicated that (in the studied population) associative effects were, after one generation of selection, most related to oral manipulative behaviour, and to a lesser extent to aggressive behaviour (Camerlink et al., 2015). Other studies in which pigs were not selected for associative effects but estimates of their so-called ‘social breeding value’ were available, showed that pigs with a positive social breeding value (indicating a positive effect on the growth rate of its pen mates) showed more aggression at regrouping but less aggression later on, suggesting an improved ability to form dominance relationships (Rodenburg et al., 2010; Canario et al., 2012). Application of this method requires accurate pen identity information for all pigs to estimate the heritable effect on group members. Estimates carried out in recent years by the larger pig breeding companies seem favourable and the method has been adopted by some of the global pig breeding programmes. Commercial implementation of selection on associative effects is only in its infancy but it is a promising step forward for the welfare of pigs on commercial farms as well as for farm productivity.

14.6 Conclusions and future trends

Pig breeding has a central role to play in meeting both economic and environmental demands of a human population that is both increasing in number and in affluence, and as a result, in its demand for meat products. Improved animal welfare can directly contribute to the achievement of economic and environmental sustainability goals. In future years there is likely to be a need to broaden pig breeding goals to include welfare-relevant traits in order to counter the effects of selection on productivity and to more directly improve welfare traits in their own right. Utilising breeding alongside continued effort to establish feasible management interventions may help to mitigate some of the most significant, intransigent and routine welfare challenges in commercial production. Ethical and practical barriers exist to the incorporation of welfare traits within pig breeding indexes. The ethical considerations need to be addressed by providing evidence of the likely effect of selection on the wider phenotype and on affective state. The cost of phenotyping welfare traits remains a barrier to selection. Innovations in recording methods and/or the application of modern breeding tools are expected in the future to reduce these costs sufficiently to allow selection where there is a demonstrable market demand. With modern breeding techniques comes the attendant risk of accelerating unwanted change and a need to fully assess the correlated consequences for the animals. However, where workable management solutions are yet to be found, selective breeding may have a role to play in improving long-standing, routine and serious welfare issues alongside continued efforts to find effective management solutions.

Abbreviation

SNP single nucleotide polymorphism

References

AHDB (Agriculture and Horticulture Development Board), 2015. BPEX Year Book 2014–2015. Agriculture and Horticulture Development Board, Kenilworth, UK.

Arey, D.S., Edwards, S.A., 1998. Factors influencing aggression between sows after mixing and the consequences for welfare and production. Livest. Prod. Sci. 56, 61–70.

Balaban, E., Alper, J.S., Kasamon, Y.L., 1996. Mean genes and the biology of aggression: a critical review of recent animal and human research. J. Neurogenet. 11, 1–43.

Baxter, E.M., Jarvis, S., D'Eath, R.B., Ross, D.W., Robson, S.K., Farish, M., Nevison, I.M., Lawrence, A.B., Edwards, S.A., 2008. Investigating the behavioural and physiological indicators of neonatal survival in pigs. Theriogenology 69, 773–783. Available from: http://dx.doi.org/10.1016/j.theriogenology.2007.12.007.

Baxter, E.M., Jarvis, S., Sherwood, L., Farish, M., Roehe, R., Lawrence, A.B., Edwards, S. A., 2011. Genetic and environmental effects on piglet survival and maternal behaviour of the farrowing sow. Appl. Anim. Behav. Sci. 130, 28–41.

Baxter, E.M., Edwards, S.A., 2017. Piglet mortality and morbidity: inevitable or unacceptable? In: Špinka, M. (Ed.), Advances in Pig Welfare. Woodhead Publishing, Duxford, UK.

Bergsma, R., Kanis, E., Knol, E.F., Bijma, P., 2008. The contribution of social effects to heritable variation in finishing traits of domestic pigs (*Sus scrofa*). Genetics 178, 1559–1570.

Berry, D.P., Meade, K.G., Mullen, M.P., Butler, S., Diskin, M.G., Morris, D., Creevey, C.J., 2011. The integration of 'omics' disciplines and systems biology in cattle breeding. Animal 5, 493–505.

Bijma, P., 2010. Estimating indirect genetic effects: precision of estimates and optimum designs. Genetics 186, 1013–1028.

Bijma, P., Muir, W.M., Van Arendonk, J.A.M., 2007. Multilevel selection 1: Quantitative genetics of inheritance and response to selection. Genetics. 175, 277–288.

Breuer, K., Sutcliffe, M.E.M., Mercer, J.T., Rance, K.A., O'Connell, N.E., Sneddon, I.A., Edwards, S.A., 2005. Heritability of clinical tail-biting and its relation to performance traits. Livest. Prod. Sci. 93, 87–94.

Broom, D.M., 2010. Animal welfare: an aspect of care, sustainability, and food quality required by the public. J. Vet. Med. Educ. 37, 83–88.

Brunberg, E., Jensen, P., Isaksson, A., Keeling, L.J., 2013a. Brain gene expression differences are associated with abnormal tail biting behavior in pigs. Genes Brain Behav. 12, 275–281.

Brunberg, E., Jensen, P., Isaksson, A., Keeling, L.J., 2013b. Behavioural and brain gene expression profiling in pigs during tail biting outbreaks-evidence of a tail biting resistant phenotype. PLoS One. 8, e66513.

Camerlink, I., Ursinus, W.W., Bijma, P., Kemp, B., Bolhuis, J.E., 2015. Indirect genetic effects for growth rate in domestic pigs alter aggressive and manipulative biting behaviour. Behav. Genet. 45, 117–126.

Canario, L., Lundgren, H., Haandlykken, M., Rydhmer, L., 2010. Genetics of growth in piglets and the association with homogeneity of body weight within litters. J. Anim. Sci. 88, 1240–1247.

Canario, L., Turner, S.P., Roehe, R., Lundeheim, N., D'Eath, R.B., Lawrence, A.B., Lawrence, A.B., Knol, E., Bergsma, R., Rydhmer, L., 2012. Genetic relationships between behaviour and direct and social genetic effects on growth rate in pigs. J. Anim. Sci. 90, 4706–4715.

Cherel, P., Pires, J., Glénisson, J., Milan, D., Iannuccelli, N., Hérault, F., Damon, M., Le Roy, P., 2011. Joint analysis of quantitative trait loci and major effect causative mutations affecting meat quality and carcass composition traits in pigs. BMC Genet. 12, 76.

Damgaard, L.H., Rydhmer, L., Løvendahl, P., Grandinson, K., 2003. Genetic parameters for within-litter variation in piglet birth weight and change in within-litter variation during suckling. J. Anim. Sci. 81, 604–610.

D'Eath, R.B., Roehe, R., Turner, S.P., Ison, S.H., Farish, M., Jack, M.C., Lundeheim, N., Rydhmer, L., Lawrence, A.B., 2009. Genetics of animal temperament: aggressive behaviour at mixing is genetically associated with the response to handling in pigs. Animal 3, 1544–1554.

D'Eath, R.B., Conington, J., Lawrence, A.B., Olsson, I.A.S., Sandøe, P., 2010. Breeding for behavioural change in farm animals: practical, economic and ethical considerations. Anim. Welfare 19, 17–27.

D'Eath, R.B., Arnott, G., Turner, S.P., Jensen, T., Lahrmann, H.P., Busch, M.E., Niemi, J.K., Lawrence, A.B., Sandøe, P., 2014. Injurious tail biting in pigs: How can it be controlled in existing systems without tail docking? Animal 8, 1479–1497.

D'Eath, R.B., Niemi, J.K., Vosough Ahmadi, B., Rutherford, K.M.D., Ison, S.H., Turner, S. P., Anker, H.T., Jensen, T., Busch, M.E., Jensen, K.K., Lawrence, A.B., Sandøe, P., 2016. Why are most EU pigs still tail docked? – economic and ethical assessment of four pig housing and management scenarios in the light of EU directives and animal welfare outcomes. Animal. 10, 687–699.

Desire, S., Turner, S.P., D'Eath, R.B., Doeschl-Wilson, A.B., Lewis, C.R.G., Roehe, R., 2015. Genetic associations of short- and long-term aggressiveness identified by skin lesions with growth, feed efficiency and carcass characteristics in growing pigs. J. Anim. Sci. 93, 3303–3312.

EFSA, 2007. The risks associated with tail biting in pigs and possible means to reduce the need for tail docking considering the different housing and husbandry systems (Question No EFSA-Q-2006-013). Annex EFSA J. 611, 1–13.

Ellen, E.D., Rodenburg, T.B., Albers, G.A.A., Bolhuis, J.E., Camerlink, I., Duijvesteijn, N., Knol, E.F., Muir, W.F., Peeters, K., Reimert, I., Sell-Kubiak, E., vanArendonk, J.A.M., Visscher, J., Bijma, P., 2014. The prospect of selection for social genetic effects to improve welfare and productivity in livestock. Front. Genet.. Available from: http://dx.doi.org/10.3389/fgene.2014.00377.

Falconer, D.S., Mackay, T.F.C., 1996. Introduction to Quantitative Genetics, fourth ed. Longman, New York.

Fernandez, X., Meunier-Salaun, M.C., Morméde, P., 1994. Agonistic behaviour, plasma stress hormones, and metabolites in response to dyadic encounters in domestic pigs: interrelationships and effect of dominance status. Physiol. Behav. 56, 841–847.

Garreau, H., Bolet, G., Larzul, C., Robert-Granie, C., Saleil, G., SanCristobal, M., Bodin, L., 2008. Results of four generations of a canalising selection for rabbit birth weight. Livest. Sci. 119, 55–62.

Goddard, M.E., 2009. View to the future: Could genomic evaluation become the standard? Proceedings of the Interbull International Workshop on Genomic Information in Genetic Evaluations, Uppsala. Bulletin 39, 83–88.

Grandison, K., Rydhmer, L., Strandberg, E., Solanes, F.X., 2005. Genetic analysis of body condition in the sow during lactation, relationship to piglet survival and growth. Anim. Sci. 80, 33–40.

Griffing, B., 1967. Selection in reference to biological groups I. Individual and group selection applied to populations of unordered groups. Aust. J. Biol. Sci. 20, 127–140.

Gronskyte, R., Clemmensen, L.H., Hviid, M.S., Kulahci, M., 2016. Monitoring pig movement at the slaughterhouse using optical flow and modified angular histograms. Biosyst. Eng. 141, 19–30.

Harley, S., More, S.J., O'Connell, N.E., Hanlon, A., Teixeira, D., Boyle, L., 2012. Evaluating the prevalence of tail biting and carcass condemnations in slaughter pigs in the Republic and Northern Ireland, and the potential of abattoir mean inspection as a welfare surveillance tool. Vet. Rec. 171, 621–627.

Hermesch, S., Li, L., Doeschl-Wilson, A.B., Gilbert, H., 2015. Selection for productivity and robustness traits in pigs. Anim. Prod. Sci. 55, 1437–1447.

Jensen, P., 2010. Domestication, selection, behaviour and welfare of animals – genetic mechanisms for rapid responses. Anim. Welfare 19, 7–9.

Kanis, E., De Greef, K.H., Hiemstra, A., van Arendonk, J.A.M., 2005. Breeding for societally important traits in pigs. J. Anim. Sci. 83, 948–957.

Kapell, D.N., Ashworth, C.J., Knap, P.W., Roehe, R., 2011. Genetic parameters for piglet survival, litter size and birth weight or its variation within litter in sire and dam lines using Bayesian analysis. Livest. Sci. 135, 215–224.

Keeling, L.J., 2005. Healthy and happy: animal welfare as an integral part of sustainable agriculture. AMBIO 34, 316–319.

Knap, P.W., 2005. Breeding robust pigs. Anim. Prod. Sci. 45, 763–773.

Kritas, S.K., Morrison, R.B., 2007. Relationships between tail biting in pigs and disease lesions and condemnations at slaughter. Vet. Rec. 160, 149–152.

Lawrence, A.B., Conington, J., Simm, G., 2004. Breeding and animal welfare: practical and theoretical advantages of multi-trait selection. Anim. Welfare 13, S191–S196.

Mauget, R., 1981. Behavioural and reproductive strategies in wild forms of *Sus scrofa* (European Wild Boar and feral pigs). In: Sybesma, W. (Ed.), The Welfare of Pigs. A Seminar in the EEC Program of Coordination of Research on Animal Welfare, Brussels. Martinus Nijhoff Publishers, London, pp. 3–13.

Mendl, M., 1995. The social behaviour of non-lactating sows and its implications for managing sow aggression. Pig J. 34, 9–20.

Mohrmann, M., Roehe, R., Knap, P.W., Looft, H., Plastow, G.S., Kalm, E., 2006. Quantitative trait loci associated with AutoFOM grading characteristics, carcass cuts and chemical body composition during growth of Sus scrofa. Anim. Genet. 37, 435–443.

Morméde, P., Foury, A., Terenina, E., Knap, P., 2011. Breeding for robustness: the role of cortisol. Animal 5, 651–657.
Muir, W.M., 2005. Incorporation of competitive effects in forest tree or animal breeding programs. Genetics 170, 1247–1259.
Munsterhjelm, C., Simola, O., Keeling, L., Valros, A., Heinonen, M., 2013. Health parameters in tail biters and bitten pigs in a case-control study. Animal 7, 814–821.
Nasirahmadi, A., Hensel, O., Edwards, S.A., Sturm, B., 2016. Automatic detection of mounting behaviours among pigs using image analysis. Comput. Electron. Agric. 124, 295–302.
Rauw, W.M., Kanis, E., Noordhuizen-Stassen, E.N., Grommers, F.J., 1998. Undesirable side effects of selection for high production efficiency in farm animals: a review. Livest. Prod. Sci. 56, 15–33.
Rodenburg, T.B., Bijma, P., Ellen, E.D., Bergsma, R., de Vries, S., Bolhuis, J.E., Kemp, B., van Arendonk, J.A.M., 2010. Breeding amiable animals? Improving farm animal welfare by including social effects in breeding programmes. Anim. Welfare 19 (S), 77–82.
Roehe, R., Kalm, E., 2000. Estimation of genetic and environmental risk factors associated with pre-weaning mortality in piglets using generalized linear mixed models. Anim. Sci. 70, 227–240.
Roehe, R., Shrestha, N.P., Mekkawy, W., Baxter, E.M., Knap, P.W., Smurthwaite, K.M., Jarvis, S., Edwards, A.B., Smurthwaite, S.A., 2009. Genetic analyses of piglet survival and individual birth weight on first generation data of a selection experiment for piglet survival under outdoor conditions. Livest. Sci. 121, 173–181.
Roehe, R., Shrestha, N.P., Mekkawy, W., Baxter, E.M., Knap, P.W., Smurthwaite, K.M., Jarvis, S., Edwards, A.B., Smurthwaite, S.A., 2010. Genetic parameters of piglet survival and birth weight from a two-generation crossbreeding experiment under outdoor conditions designed to disentangle direct and maternal effects. J. Anim. Sci. 88, 1276–1285.
Rundgren, M., Löfquist, I., 1989. Effects on performance and behaviour of mixing 20kg pigs fed individually. Anim. Prod. 49, 311–315.
Rutherford, K.M.D., Baxter, E.M., D'Eath, R.B., Turner, S.P., Arnott, G., Roehe, R., Ask, B., Sandøe, P., Moustsen, V.A., Thorup, F., Edwards, S.A., Berg, P., Lawrence, A.B., 2013. The welfare implications of large litter size in the domestic pig I: biological factors. Anim. Welfare 22, 199–218.
Rydhmer, L., 2000. Genetics of sow reproduction, including puberty, oestrus, pregnancy, farrowing and lactation. Livest. Prod. Sci. 66, 1–12.
Sandøe, P., Nielsen, B.L., Christensen, L.G., Sorensen, P., 1999. Staying good while playing God – the ethics of breeding farm animals. Anim. Welfare 8, 313–328.
Sinisalo, A., Niemi, J.K., Heinonen, M., Valros, A., 2012. Tail biting and production performance in fattening pigs. Livest. Sci. 143, 220–225.
Statham, P., Green, L., Bichard, M., Mendl, M., 2009. Predicting tail-biting from behaviour of pigs prior to outbreaks. Appl. Anim. Behav. Sci. 121, 157–164.
Su, G., Lund, M.S., Sorensen, D., 2007. Selection for litter size at day five to improve litter size at weaning and piglet survival rate. J. Anim. Sci. 85, 1385–1392.
Tan, S.S.L., Shackleton, D.M., Beames, R.M., 1991. The effect of mixing unfamiliar individuals on the growth and production of finishing pigs. Anim. Prod. 52, 201–206.
Taylor, N.R., Main, D.C.J., Mendl, M., Edwards, S.A., 2010. Tail-biting: a new perspective. Vet. J. 186, 137–147.
Turner, S.P., Farnworth, M.J., White, I.M.S., Brotherstone, S., Mendl, M., Knap, P., Penny, P., Lawrence, A.B., 2006. The accumulation of skin lesions and their use as a predictor of individual aggressiveness in pigs. Appl. Anim. Behav. Sci. 96, 245–259.

Turner, S.P., Roehe, R., D'Eath, R.B., Ison, S.H., Farish, M., Jack, M.C., Lundeheim, N., Rydhme, L., Lawrence, A.B., 2009. Genetic validation of post-mixing skin injuries in pigs as an indicator of aggressiveness and the relationship with injuries under more stable social conditions. J. Anim. Sci. 87, 3076−3082.

Valros, A., 2017. Tail biting. In: Špinka, M. (Ed.), Advances in Pig Welfare. Woodhead Publishing, Duxford, UK.

Van Rens, B.T.T.M., De Koning, G., Bergsma, R., Van Der Lende, T., 2005. Preweaning piglet mortality in relation to placental efficiency. J. Anim. Sci. 83, 144−151.

Viazzi, S., Ismayilova, G., Oczak, M., Sonoda, L.T., Fels, M., Guarino, M., Vranken, E., Hartung, J., Bahr, C., Berckmans, D., 2014. Image feature extraction for classification of aggressive interactions among pigs. Comput. Electron. Agric. 104, 57−62.

Verdon, M., Rault, J.L., 2017. Aggression in group housed sows and fattening pigs. In: Špinka, M. (Ed.), Advances in Pig Welfare. Woodhead Publishing, Duxford, UK.

Wall, E., Simm, G., Moran, D., 2010. Developing breeding schemes to assist mitigation of greenhouse gas emissions. Animal 4, 366−376.

Wallenbeck, A., Rydhmer, L., Lundeheim, N., 2009. GxE interactions for growth and carcass leanness: re-ranking of boars in organic and conventional pig production. Livest. Sci. 123, 154−160.

Wilson, K., Zanella, R., Ventura, C., Johansen, H.L., Framstad, T., Janczak, A., Zanella, A. J., Neibergs, H.L., 2012. Identification of chromosomal locations associated with tail biting and being a victim of tail-biting behaviour in the domestic pig (*Sus scrofa domesticus*). J. Appl. Genet. 53, 449−456.

Zonderland, J.J., van Riel, J.W., Bracke, M.B.M., Kemp, B., den Hartog, L.A., Spoolder, H. A.M., 2009. Tail posture predicts tail damage among weaned piglets. Appl. Anim. Behav. Sci. 121, 165−170.

Pigs as laboratory animals

16

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16.1 Introduction

The majority of this book has focused on the pig as a meat-producing animal. In this chapter, we argue that the pig is indeed unique, because of a combined use for meat production as well as for research, which is not normally seen in domestic animals. The pig, however, shares large anatomical and physiological homologies with humans, which have driven the increasing use of this animal species as an animal model (Swindle and Smith, 2015). Today, the pig is recognised as an advantageous nonrodent animal model within a large number of biomedical research areas (as reviewed by Roth and Tuggle, 2015). In addition, the pig is the leading animal species within studies of xenotransplantation of animal organs into humans (Schook et al., 2005). Across these multiple research areas, the size similarity between pigs and man is a clear advantage (Søndergaard and Herskin, 2012), allowing the use of human devices combined with access to relatively large volumes of body fluids and tissue (Nunoya et al., 2007).

Compared to the traditional laboratory rodents, the main biomedical purpose of which are to model human conditions, the important role of the pig as meat-producing animal means that pigs are also subject of research in their own rights – for example in studies of porcine nutrition (Lærke et al., 2015), diseases (Mustonen et al., 2012) or housing (as surveyed by Ganderup, 2015). Even though all these research areas share the use of pigs, it is important to emphasise that a large number of pig breeds are available and used for research, each with distinct characteristics, and highly variable body sizes – from micro pigs to the traditional farmed breeds (as reviewed by McCrackin and Swindle (2015) and Ganderup (2015)).

As discussed in the earlier chapters of this book, the welfare of the large breeds of pigs kept as meat-producing animals have received scientific as well as public attention for decades (Pedersen, Chapter 1: Overview of commercial pig production systems and their main welfare challenges; Lawrence et al., Chapter 15: Positive pig welfare), and at present international as well as national legal requirements aim to ensure pig welfare. More recently, a number of technical guidelines and health-care programs for the management of swine in research have been published (Bollen et al., 2000; Laber et al., 2002). However, as discussed by Søndergaard et al. (2011), the level of reporting on welfare of laboratory pigs in biomedical studies has been strikingly low. In this chapter, we aim to combine knowledge from studies of farmed as well as laboratory pigs in a discussion of central aspects of pig welfare considered relevant for pigs kept for research purposes.

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16.2 Monitoring of laboratory pig welfare

When using animals for experimental purposes, one has legal, ethical as well as scientific responsibilities to ensure and document the welfare standard for the concerned individuals – for the sake of the pigs, but also due to the potential effects of the animal welfare state on the scientific outcomes. In many regions of the world, experimental animals maintain special legal protection (as compared to animals kept for food or companion animals). One such example is the obligation for animal studies to undergo ethical review including justification of the expected aims, documentation of the severity of the planned procedures, and establishment of humane endpoints. The latter constitute predetermined clinical criteria for the exclusion of animals from studies (most often followed by immediate euthanasia), in order to limit suffering. Additionally, in many regions of the world, researchers have a legal requirement to comply with the 3Rs (as originally proposed by Russell and Burch, 1959): replace the use of live animals as much as possible, reduce the number of animals used, and – more relevant for this chapter – to refine the techniques and procedures involving animals as much as possible, in order to minimise the welfare burden for the animals. Without questioning the original intentions underlying the 3Rs, we would, however, like to draw attention to more recent publications discussing relations between the 3Rs and animal welfare (such as Rusche (2003) or Olsson et al. (2012)).

In order to perform animal experiments in compliance with the mentioned requirements, the welfare of the experimental animals must be monitored. Within the field of biomedicine, The Federation of European Laboratory Animal Science Associations (FELASA) has issued guidelines on how to monitor health of pigs (Rehbinder et al., 1998). However, less attention has been given to other aspects of porcine welfare. In fact, as discussed by Søndergaard et al. (2011), at present no validated welfare monitoring tools have been published for laboratory pigs, and in the majority of the recent papers presenting results from in vivo porcine studies, no such monitoring has been described. Taking the large focus on welfare of pigs kept as meat-producing animals, and the availability of welfare scoring systems for pigs kept for these purposes (e.g., Welfare Quality (2009) which involves animal-based as well as resource-based measures), into account, such lack of validated protocols for monitoring of the welfare of laboratory pigs is surprising.

For legislative purposes, there is often a focus on 'input' resource-based measures – i.e. measurement of physical resources that should be provided to the animal in order to safeguard its welfare, rather than 'output' animal-based measures – i.e. direct measures of the animal's behaviour or health (Main et al., 2007). Although more recently there has been the development of assessment protocols that focus more on animal-based measures, such as the Welfare Quality ones, they still have some limitations in on-farm settings, due to the sheer number of animals on a given farm and the time required to carry them out. In the laboratory setting, where numbers of animals and caretakers are shifted much more towards the individual animal, the monitoring of the welfare of individuals should be more simple to achieve. There are examples of studies reporting the development of porcine perioperative care based on series of cases (Murison et al., 2009), as well as recommendations for postoperative monitoring during the anaesthetic phase and in the hours after anaesthesia (Swindle and Sistino, 2015). For longer-term studies, Swindle and Sistino (2015) recommend development of study specific monitoring tools involving clinical and behavioural indicators in order to determine the welfare state of the animals throughout a study period. As health and welfare are entangled concepts (Broom, 2006), it is important to state that a systematic assessment of animal welfare necessitates knowledge about, and ability to interpret, the biology of the involved animal species, its species-specific behaviour and clinical symptoms.

One suggested basis for such development of a welfare monitoring tool, could be a combination of, and redevelopment of, the welfare indicators validated for farmed pigs (where focus is often put at pen level (e.g. Welfare Quality, 2009)) and clinical health indicators used in studies of toxicology (Helke, 2015) or clinical studies of pigs after experimental infection (Mustonen et al., 2012). It is important to emphasise that even though, traditionally and legally, it is accepted that healthy pigs kept for meat production are checked by the farmer once per day, laboratory pigs may need scoring of their conditions considerably more frequently. As discussed by Murison et al. (2009) for airway research, an appropriate welfare monitoring tool must be adapted to the specific experimental conditions bearing in mind that the range of research areas involving pigs covers different potential challenges to animal welfare, such as tissue damage or type of housing. As an example, tissue damage may be graded from mild (such as being exposed to UVB-light (Di Giminiani et al., 2014)) to moderate (such a tail docking as part of research into husbandry procedures (Marchant-Forde et al., 2009)) or even severe (such as spinal cord injury (Navarro et al., 2012)). Recently, Olsen et al. (2016) used the preformulated humane endpoints to conclude that they could not justify further use of a conscious porcine model of severe sepsis. The fact that the pig is often considered robust to welfare challenges (as proposed by Navarro et al., 2012) means that welfare indicators such a death or decreased growth should not stand alone, but must be supported by more sensitive clinical, behavioural and resource-based indicators in order to achieve a tool of appropriate sensitivity. The literature covering the welfare of pigs as meat-producing animals carries many examples of potential welfare indicator candidates, which are also relevant for pigs kept as laboratory animals, including animal-based, management-based and resource-based indicators. Hence, a future scientific development and validation of a welfare monitoring tool for pigs used in research should take the available knowledge from farmed pigs into account.

16.3 Welfare and housing

Housing for the laboratory pig often meets the concept of traditional laboratory animal housing, i.e. housing that is sterile, isolated, easy to manage, environmentally-controlled and built for the specific needs of the caretaker and for the procedures which the pig will undergo (see Fig. 16.1).

Figure 16.1 Example of raised floor housing pens for laboratory pigs.
Sources: www.altdesign.com, www.lenderking.com.

There is also the long-running belief that for laboratory animal studies to be reproducible, there should be environmental standardisation and that this is best achieved by having homogenous housing conditions. As we now know, such standardisation can actually be detrimental to reproducibility (Richter et al., 2009) and that systematic variation of environmental conditions such as enrichment, enclosure size, sound and lighting can actually be beneficial (Richter et al., 2010).

Handbooks on the care of laboratory pigs vary in the amount of detail given about housing requirements dependent on whether they are written by industry bodies or NGOs concerned with the welfare of laboratory animals. For example, the National Research Council of the National Academies' Guide for the Care and Use of Laboratory Animals (ILAR, 2011) contains much use of the terms 'adequate' and 'appropriate' in its descriptions of the animal's microenvironment being only specific for pigs in documenting minimum space requirements and that they should be provided with manipulable toys.

Other handbooks or guides (e.g., Holtz, 2010; RSPCA, 2011; Skoumbourdis, 2015) contain more detail, giving an outline of the pig's nature and how it applies to the design of housing and management systems that will safeguard its welfare, such as social living, thermal and physical comfort and stimulating enrichment. This section will cover how the environment of the laboratory pig may impact its welfare.

16.3.1 Comfort, sterility and hygiene

The thermal and physical comfort of the laboratory pig can be greatly influenced by elements of the environment, such as flooring, bedding substrates and social housing. The Guide for the Care and Use of Laboratory Animals (ILAR, 2011) describes an enclosure that 'should be made of durable, nontoxic materials' and that 'flooring should be solid, perforated, or slatted with a slip-resistant surface.' Many of the purpose-built laboratory pig housing pens (see Fig. 16.1) combine fully-slatted flooring with solid metal sides, clearly designed to meet the caretakers' needs rather than the pigs'. If housed individually in such pens, it is crucially important that the thermal environment of the room falls within the thermoneutral zone of the pig, given its age and size, as there is little ability for the pig to regulate its own thermal comfort, by wallowing or huddling. Both heat stress (Muns et al., 2016a) and cold stress (Muns et al., 2016b), due to the fact that pigs lack sweat glands and consequently need to thermoregulate behaviourally (Ingram, 1965), have large welfare implications for pigs, resulting in physiological and behavioural changes and increased morbidity and mortality.

Building using design elements that allow the pig a choice in thermal environment will improve welfare. This could be achieved by either providing zones with differing temperatures – pigs will choose temperatures that are more comfortable (Vasdal et al., 2010), or by maintaining temperature and offering choice in floor substrate. Day-old piglets kept at a constant 34°C preferred sawdust on a solid floor over either foam or a water-filled mattress (Vasdal et al., 2010), whereas older pigs (3–4 months old) kept at 18°C preferred sawdust on a solid floor over solid or slatted concrete, but when the temperature was raised to 27°C, the preference reversed and the non-bedded floor was preferred (Ducreux et al., 2002). The importance for a pig to have a degree of ability to control its thermal environment can be illustrated by the classic experiments detailed by Baldwin (1979). When trained to operate radiant heaters by pressing a panel switch, pigs will activate the heater, with the amount of use influenced by such things as environmental temperature and metabolic heat production as a result of feed intake.

Bedding or flooring type may not only confer advantages in terms of thermal comfort, but can also offer physical comfort and be a source of environmental enrichment (see below). Hard flooring is known as a risk factor for physical injuries such as decubital shoulder ulcers (Herskin et al., 2011), claw lesions (Jensen and Toft, 2009) and forelimb skin abrasions (Mouttotou et al., 1999). Adding a bedding substrate such as straw, shavings or sawdust can improve the comfort of the pig. Although there are hygiene concerns when using organic material such as straw for bedding leading to an increase in some illnesses (see discussion in Tuyttens, 2005), there is also strong evidence that straw especially can decrease prevalence of other conditions, such as leg and hoof injuries (Andersen and Bøe, 1999), influenza (Ewald et al., 1994), tail-biting (Van de Weerd et al. (2005); Valros, Chapter 5: Tail biting) and gastrointestinal disorders, including stomach ulcers (Herskin et al., 2016).

However, the addition of organic bedding increases cost and labour requirements and requires the regular introduction of external material into what may be a biosecure environment. An alternative could be the use of rubber or plastic-coated foam matting. Within commercial pig production, mats have been shown to improve the comfort of gestating sows (Tuyttens et al., 2008, Elmore et al., 2010), farrowing sows (Boyle et al., 2000), finishing pigs (Savary et al., 2011) and preweaned piglets

(Gu et al., 2010), with the added advantage over fully-slatted steel flooring of demonstrated reduced diarrhoea morbidity in the piglet study (Gu et al., 2010). Within a laboratory pig setting, mats have been shown to be preferred compared to slatted flooring (DeBoer et al., 2013) and when combined with a mirror, to reduce plasma cortisol concentrations and other measures of stress or poor welfare when compared with pigs housed with neither mat nor mirror (DeBoer et al., 2015).

16.3.2 Barren environments and environmental enrichment

Ideally, the laboratory pig will be housed in a complex environment with access to space, companions, bedding, rooting material, unrestricted food and water, vegetation, a wallow, etc. However, the reality is that the traditional laboratory pig environment is a barren environment, meeting the needs of the caretaker, rather than the needs of the pig, as illustrated in Fig. 16.1. As such, much of the focus within a laboratory setting will be on point-source enrichment – that is enrichment objects or racks/dispensers that are generally size-limited and presented in a given location within the pen, although all effort should be made to incorporate bedding.

Keeping animals in barren environments can lead to behavioural problems, boredom and poor welfare, but these issues can be ameliorated by the use of environmental enrichment. Environmental enrichment can be defined as ‘an improvement in the biological functioning of captive animals resulting from modifications to their environment’ (Newberry, 1995). The key part of this definition is the improvement in biological functioning. The addition of any complexity into a barren environment does not necessarily improve it, and complexity must be reviewed in terms of biological relevance to the animal and its ability to improve the animal’s quality of life.

Würbel and Garner (2007) classify enrichments into 3 classes: pseudo-enrichments (‘never biologically relevant, and either neutral or even detrimental to animal welfare’), conditionally-beneficial enrichments (‘biologically relevant, but may induce welfare problems if not properly managed’), and beneficial enrichments (‘biologically relevant, beneficial to animal welfare, and rarely if ever associated with welfare problems’). Although their paper is focused on laboratory rodents, the principles hold true for laboratory pigs. As an example of pseudo-enrichment, adding marbles to a rodent’s cage, rather than improving welfare, actually induces stress (De Boer and Koolhaas, 2003) and the rodents will bury the marbles to remove the stressor (defensive burying). As an example of conditionally-beneficial enrichment, adding shelters to cages for male mice may result in the introduction of a defendable resource that can increase aggression (Nevison et al., 1999). Nesting material is a beneficial enrichment.

So for the pig, what constitutes a beneficial enrichment? What is biologically relevant to the pig, beneficial to the pig’s welfare and rarely, if ever, associated with welfare problems? The natural behaviour of the pig has been covered in detail elsewhere (D’Eath and Turner, 2009), but in summary, we have a woodland-dwelling, social animal that spends a large amount of its time foraging, using its snout and mouth to investigate. The pig has an extensive behavioural repertoire, and its primary sense is olfaction. It establishes stable family groups, which are hierarchical, avoiding unfamiliar pigs and accessing resources based on social status, which is reinforced without overt aggression. For an enrichment to be relevant, it needs to have properties that allows a pig to ‘express key elements of its behavioural repertoire’ (van de Weerd et al., 2003), and much of the focus with pigs has been on items that address its foraging and exploratory nature.

Within the European Union, the issue of environmental enrichment in commercial pig production has received a large amount of attention due to its relationship with tail-biting and the desired intent to eradicate the painful procedure of tail docking Valros, Chapter 5: Tail biting. A full scientific report on these interacting issues is available (EFSA AHAW Panel, 2014) and the contents of a Commission Staff Working Document (EU, 2016a) has been formulated into a Commission Recommendation (EU 2016/336) which gives detail on what constitutes good environmental enrichment for pigs (EU 2016b):

‘**4.** Enrichment materials should enable pigs to fulfil their essential needs without compromising their health. For that purpose, enrichment materials should be safe and have the following characteristics:
- **a.** Edible – so that pigs can eat or smell them, preferably with some nutritional benefits;
- **b.** Chewable – so that pigs can bite them;
- **c.** Investigable – so that pigs can investigate them;
- **d.** Manipulable – so that pigs can change their location, appearance or structure.

5. In addition to the characteristics listed in paragraph 4, enrichment materials should be provided in such a way that they are:
- **e.** of sustainable interest, that is to say, they should encourage the exploratory behaviour of pigs and be regularly replaced and replenished;
- **f.** accessible for oral manipulation;
- **g.** given in sufficient quantity;
- **h.** clean and hygienic.

6. In order to fulfil pigs’ essential needs enrichments material should meet all the characteristics listed in paragraphs 4 and 5. To that end, enrichments materials should be categorised as:
- **i.** optimal materials – materials possessing all the characteristics listed in paragraphs 4 and 5 and therefore such materials can be used alone;
- **j.** suboptimal materials – materials possessing most of the characteristics listed in paragraphs 4 and 5 and therefore such materials should be used in combination with other materials;
- **k.** materials of marginal interest – materials providing distraction for pigs which should not be considered as fulfilling their essential needs and therefore optimal or suboptimal materials should also be provided.’

Many of the ‘enrichment’ items sold by laboratory animal equipment retailers often address only one or two of the key characteristics in that they are chewable and/or investigable (Fig. 16.2; see also Bracke, Chapter 6: Chains as proper enrichment for intensively-farmed pigs?). They will get some interest from pigs when added to a barren environment but that interest will decrease over time as the novelty wears off (e.g. see Smith et al., 2009) and as such would qualify only as marginal enrichments, as set out in Table 16.1 taken from the Commission Staff Working Document (EU, 2016a).

Figure 16.2 Examples of traditional enrichment items sold by laboratory animal equipment manufacturers.
Sources: www.labsupplytx.com, www.ottoenvironmental.com, www.animalspecialties.biz.

The fact that laboratory pig s are usually housed in much smaller numbers than commercial pigs does have its advantages. The number of options that are practical to employ is greater and as pigs may be housed individually or in very small groups, the risk of the enrichment becoming a defendable resource is decreased. Some examples of enrichment objects known to have value in commercial settings include wood and straw racks (Telkanranta et al., 2014 – Fig. 16.3A) and the EasyFix™ toy (O'Driscoll 2015 – Fig. 16.3B). Another option may be the placement of a snout-operated pellet dispenser (Fig. 16.3C), which can be made by cutting a 30 to 60 cm section of PVC pipe, adding cap ends and drilling 2 cm holes throughout PVC. The pipe is then filled with treats and can be left on the floor or mounted on the wall in a way to enable the pipe to rotate. Pigs will have to root and turn the pipe to allow the treats to fall out.

In general, there is little research available on enrichment for pigs specifically housed as laboratory animals. There are good guidelines for enrichment for pigs

Table 16.1 Possible enrichment materials used for pigs and their interest as enrichment material

Materials	Provided as	Level of interest as enrichment materials	Complementary materials
Straw, hay, silage, miscanthus, root vegetables	Bedding	Optimal	Can be used alone
Soil	Bedding	Suboptimal	Edible and chewable materials
Wood shaving	Bedding	Suboptimal	Edible and manipulable materials
Sawdust	Bedding	Suboptimal	Edible, chewable materials
Mushroom compost, peat	Bedding	Suboptimal	Edible materials
Sand and stones	Bedding	Suboptimal	Edible and chewable materials
Shredded paper	Partial bedding	Suboptimal	Edible materials
Pellet dispenser	Dispenser	Suboptimal	Depending on the amount of pellets provided
Straw, hay or silage	Rack feed or in dispenser	Suboptimal	Investigable and manipulable materials
Soft, untreated wood, cardboard, natural rope, hessian sack	Object	Suboptimal	Edible and investigable materials
Compressed straw in cylinder	Object	Suboptimal	Investigable and manipulable materials
Sawdust briquette (suspended or fixed)	Object	Suboptimal	Edible, investigable and manipulable materials
Chain, rubber, soft plastic pipes, hard plastic, hard wood, ball, salt lick	Object	Marginal	Should be completed by optimal or suboptimal materials

This list is not exhaustive and the materials are not ranked. Other materials may be used provided they meet legal requirements

housed in commercial settings, and much of this is directly applicable and transferable. However, the enrichment of perhaps tens of thousands of pigs on a single commercial farm poses very different challenges to the enrichment of a few pigs in

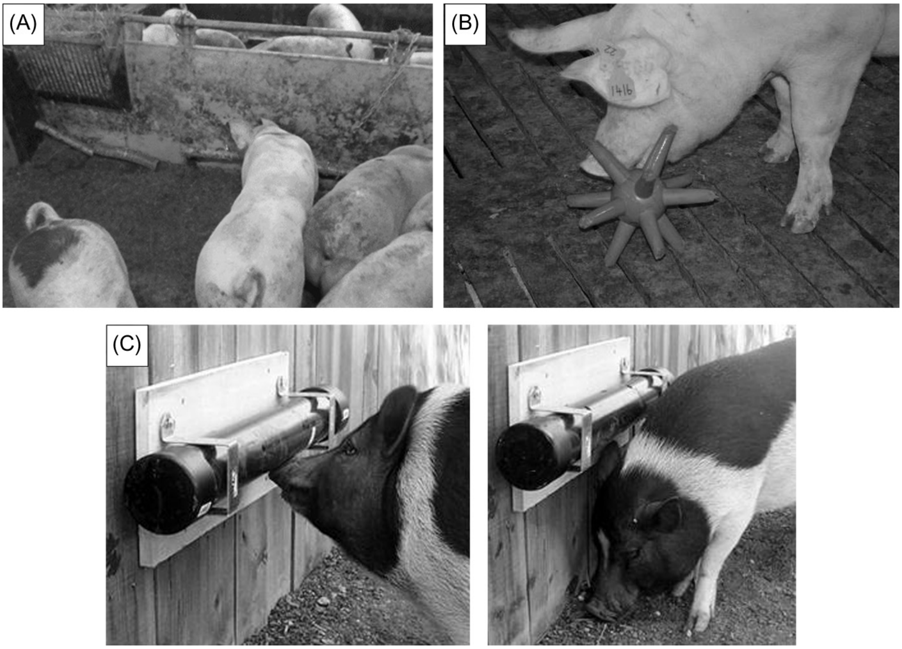

Figure 16.3 Examples of enrichment items used in commercial husbandry or smallscale/companion pig rearing, including (A) wood logs and straw rack, (B) EASYFIX® toy, and (C) treat dispenser
Sources: www.telkanranta.com, www.farewelldock.eu, www.minipiginfo.com.

a laboratory setting and there are opportunities for further development of enrichment which may only be practical in the laboratory setting. An example of this is the use of separate pens to become a designated 'playroom' through which pigs can be rotated for specific periods of time (Casey et al., 2007).

16.3.3 Social housing and social isolation

Naturally, the pig is a social animal (D'Eath and Turner, 2009), living its life in a related, usually multiaged, stable group, with the exception of mature boars which make only short-term associations with other individuals independent of kin (Podgórski et al., 2014). Given the pig's natural history, keeping pigs in commercial farming and laboratory settings poses some challenges. Within the laboratory setting, pigs may be relatively long-term residents and during this time may undergo repeated disruption of stable groups and also periods of isolation. Both of these social stressors can result in physiological and behavioural indicators of stress, impacting the animal's welfare and, potentially, health (see review by Proudfoot and Habing, 2015).

The formation of groups of pigs, and especially sows, has attracted a great deal of research in the commercial sector, given that the establishment of the social hierarchy results in aggression, which can be sustained if the environment is suboptimal. Detailed reviews of methods to ameliorate aggression at mixing are available elsewhere (Marchant-Forde and Marchant-Forde, 2005; Marchant-Forde, 2009; Spoolder et al., 2009; Verdon et al., 2015). Factors that can minimise aggression include: (1) pen designs that incorporate lots of space and, if possible, getaway areas or barriers behind which pigs can retreat, and (2) management techniques such as provision of food ad libitum around mixing, mixing in the presence of a superdominant animal, preexposing pigs to each other by penning in adjacent pens which allow communication, and allowing litters to mix as piglets to build social skills. Aggression at mixing cannot be eradicated, but once the hierarchy is established, and this takes a matter of hours only, overt aggression should be seen only occasionally. Aggression does impact welfare, especially in those individuals subject to high levels of social defeat, and may result in, for example, injury, activated HPA axis, decreased immunity and increased morbidity (see also Verdon and Rault, Chapter 8: Aggression in group housed sows and fattening pigs).

Recommendations for laboratory pigs are, wherever possible, to house pigs in groups or pairs (Holtz, 2010; ILAR, 2011; RSPCA, 2011; Skoumbourdis, 2015) and the importance of social support cannot be understated (Rault, 2012). In his review, Rault (2012) notes that the presence of a companion can increase the incidence of behavioural indicators that demonstrate the attenuation of fear and distress, and that animals exposed to stressors will actively seek company if it is available. When housed in pairs or groups, less distress vocalisations are emitted and the HPA axis shows reduced activation following exposure to stressor. Additionally, social support may result in reduced blood pressure and there is some evidence of modulated immune system function (reviewed in Rault, 2012).

Although social housing is preferred, there will be studies and procedures in the laboratory setting that requires the pig to be housed individually. For example, pigs that have undergone implantation of catheters or access ports will need to be housed alone to prevent pen-mates from damaging both the implant and the host pig (see Fig. 16.4). When housed individually, the extent to which this may impact the welfare of the pig can be influenced by the design of the pen.

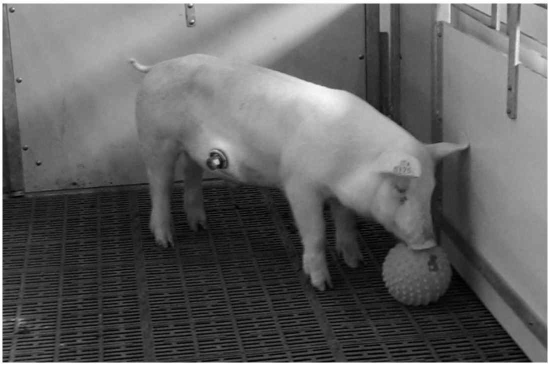

Figure 16.4 A laboratory pig fitted with a permanent T-shaped cannula in the ileum. *Source*: Helle Nygaard Lærke, Aarhus University.

Complete isolation for even a short period of time in young pigs can result in neuroendocrine and behavioural changes that indicate increased arousal and distress (Kanitz et al., 2009). Furthermore, social isolation can impact the expression of genes involved in regulation of neuronal function, development and protection (Poletto et al., 2006) and lead to long-term changes in HPA activity (Kanitz et al., 2004). The impacts of isolation on laboratory pigs have not been well studied, but there are some studies which indicate that different degrees of isolation result in different stress states. A study that compared behaviour of either fully- or partially-isolated pigs with group housed pigs, found that both isolation treatments showed an initial increase is behavioural indicators of stress, such as pawing and escape attempts and reduced play (Herskin and Jensen, 2000). After 2 weeks, those in partial isolation – separated from other pigs by wire mesh only – were still showing reduced play, but other indicators had waned, whereas those that were fully isolated – housed across the room and but able to see the other pigs – were showing further increased pawing and further reduced play. Both isolation treatments resulted in lower reactivity in a novel environment test, with reduced locomotion and reduced vocalisation, compared with group-housed pigs. Using a similar experimental setup minus the group housing treatment, and combining isolation with/without surgical catheterisation, Herskin and Hedemann (2001) found that partial isolation resulted in increased activity and increased play compared with full isolation, indicating that the provision of limited social contact may help reduce the negative effects of individual housing.

Experiments carried out by DeBoer et al. (2013, 2015) also highlight the degree to which physical isolation impacts behaviour and welfare. In the first study (DeBoer et al., 2013), individually-housed pigs were able to move between four connected, woven-wire-floored pens, each of which were slightly different. One was a control pen with four solid sides. One had a mirror and three solid sides (Fig. 16.5A). One had four solid sides and a rubber mat. One had an open side which allowed the pig to see a companion pig across the corridor. Undisturbed, the

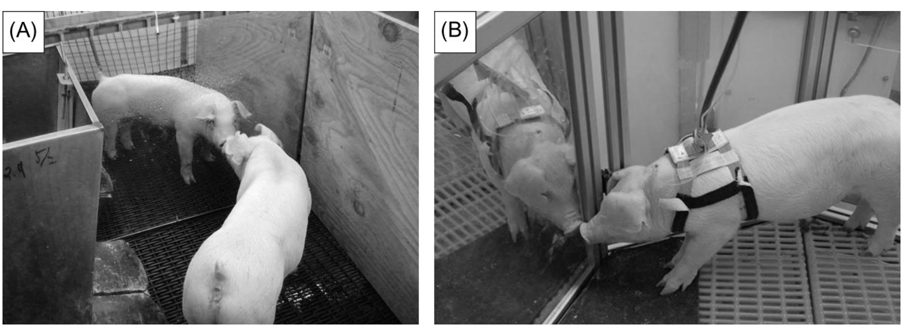

Figure 16.5 (A) A laboratory pig undergoing choice testing including a pen with a mirror, and (B) within a PigTurn® pen enriched using a mirror and a rubber mat.
Source: Shelly Pfeffer DeBoer.

pigs chose to spend more time in the pen opposite the companion and less time in the control pen, with the other two treatments intermediate. However, when a human entered the room, the amount of time spent in a pen with a social enrichment (i.e. across from the companion or with the mirror) was far greater than time spent in the other two pens, and there was no preference for companion over mirror. These results suggest that a mirror may be used by the animal for social support during periods of perceived threat. In a follow-up study, the mirror and mat were combined as an enrichment for a specialised housing system (The PigTurn® – Fig. 16.5B) which was examined in combination with isolation treatments – either visually isolated (but within the same room) or still physically isolated but able to see other pigs. The results showed that enrichment given to pigs housed in visual isolation had no effect on plasma cortisol concentrations, but greatly reduced it in the pigs able to see other pigs. Other measures suggested that in the absence of enrichment, being able to see other pigs but not physically interact was frustrating. Appropriate enrichment and proximity of another pig improved welfare. Wherever possible, tactile communication, even through mesh walls, should be practiced and mirrors used where this is not available.

16.4 Welfare and feeding

16.4.1 Dietary content

The nutritional requirements of all pigs are covered in detail within the NRC (2012) guidelines, which sets out the best estimates for minimum requirements for such constituents as proteins, minerals and vitamins and recommended energy levels and quantity of feed to be given to pigs of different age groups. Some of the summarised data are shown in Table 16.2. These data relate to growing farm pigs being fed to maximise growth, and gestating sows in the 220–250 kg bodyweight

Table 16.2 Dietary requirements of growing pigs allowed feed ad libitum (90% dry matter) and restricted fed gestating sows

Weight range of pig (kg)	ME content of diet (kcal/kg)	Estimated feed intake (g/day)	Crude protein (%)
5–7	3400	280	24–26
7–11	3400	500	22–24
11–25	3350	950	21–25
25–50	3300	1600	19.3
50–75	3300	2230	17.1
75–100	3300	2640	15.2
100–135	3300	2950	13.4
Gestating sows	3265	2000	12.2

Data adapted from NRC (National Resesarch Council of the National Academies), 2012.

range being fed to support pregnancy and maintain bodyweight and body condition.

From a laboratory pig viewpoint, the aim is not to maximise growth rates and therefore, there must be some dietary adjustment in either content or quantity in order to maintain pigs at the size and body condition required over the projected time period that they are needed. From a content aspect, the most common changes in lab pig diets compared to farm pig diets are reductions in energy and protein content and an increase in crude fibre content. For example, a typical farm pig starter diet might be expected to have 3500 kcal/kg ME, 24% crude protein and 2.5%–3% crude fibre, whereas a laboratory pig starter diet might be 3200 kcal/kg ME, 21% CP and 4% fibre. Increasing fibre content is an often-used mechanism to restrict energy intake yet maintain satiety, thereby facilitating normal behaviour (e.g. Sapkota et al., 2016). However, it must also be noted that high fibre content (15% plus) in diets may lengthen gastric emptying and intestinal transit time (Bollen et al., 2000) with subsequent impact on digestion and, potentially, digestive physiology.

16.4.2 Diet availability – restriction/ad lib feeding

As ad libitum feeding of conventional and energy-reduced diets can lead to obesity in pigs kept for laboratory purposes, quantitative reduction is achieved by restricted feeding, that is giving the pig access to a limited amount of food, once or twice a day. Without ad libitum access, the pig will be hungry for at least part of each day, which is a welfare issue. The implications of food restriction and hunger are well covered elsewhere (D'Eath et al., 2009; D'Eath et al., Chapter 7: Mitigating hunger in pregnant sows), but for the pig, which is a natural forager, having limited access to food can affect its daily time budget both in terms of amounts and types of behaviours performed. If food is not going to be available all the time, then as discussed in Section 16.3, the environment needs sufficient complexity to enable the pig to fill its time with foraging-like behaviour that will encompass substrate-directed manipulation. Without this, there is a risk of increased pen-mate-directed manipulation or development of stereotypic behaviours, both of which are indicators of poor welfare.

16.4.3 Feeding system

For pigs kept in groups, a major housing factor that impacts their welfare is that of feeding system design. If food is available ad libitum, pigs can choose when to eat and avoid conflict. Ad libitum delivery of a high fibre/low energy diet is a good method to reduce food-related aggression and hunger in slow-growing lab pigs or minipigs, but for commercial pigs used for laboratory purposes, growth may need to be controlled by restricted feeding. Where food is limited, its importance as a resource is heightened and it becomes a source of competition, which can be influenced by the way the food is delivered. Floor feeding is the simplest system but can result in high levels of aggression and it is possible for the dominant pig to monopolise the food, resulting in variable individual feed intake. Trough feeding can help spread out the food source allowing all pigs to access the food simultaneously if there is sufficient trough space per pig. Barriers along the trough can help to give separate feeding places and liquid feeding can equalise eating speed, and reduce the chance of a quick eater displacing slower eaters. Other systems used with farm pigs include feeding stalls into which individuals can be shut and electronic feeder systems, in which pigs feed sequentially. Both these types of systems have the advantage for the carer of being able to deliver different amounts to individuals based on body condition or individual needs. The relative advantages and disadvantages of feeding systems are discussed in more detail elsewhere (Marchant-Forde, 2009; Verdon and Rault, Chapter 8: Aggression in group housed sows and fattening pigs). For laboratory pigs housed individually, the issues with competition do not apply, and a simple, single-space feeder is appropriate. For studies on obesity, metabolic processes and others where monitoring of appetite and feed intake may be important, there is also the option to have feeding systems that can record meal durations and amount of food consumed. Various options are available commercially (e.g. the MP Feed Intake Monitoring system, MBRose, Faaborg, DK – see Fig. 16.6) for either individually- or group-housed pigs.

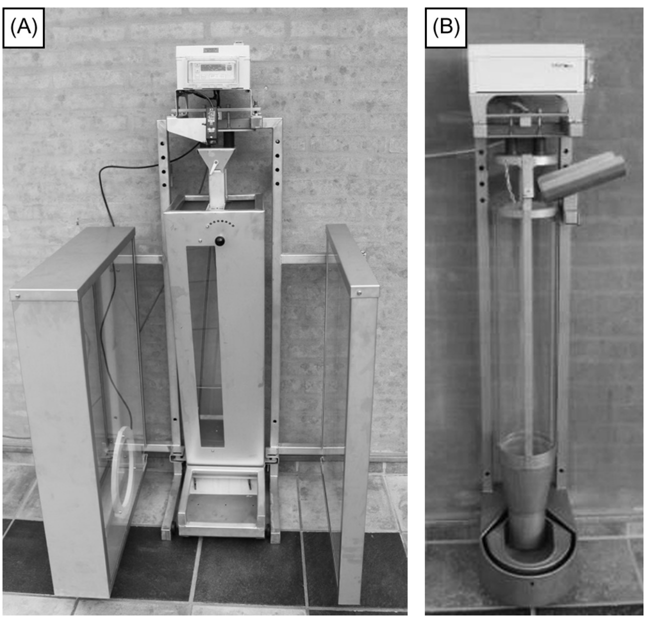

Figure 16.6 The feed intake monitor by MBRose, with (A) group-housed or (B) individually-housed configurations.
Source: www.mbrose.dk.

16.5 Welfare and human–animal interaction

The laboratory pig is in a position to receive far greater human contact than its commercial farm counterpart. A recent estimate for Dutch commercial pig production is that the caretaker has so many animals under their care that they can only spend about 1 second a day on each individual pig during the course of their daily duties (H Hogeveen, personal communication). In a laboratory pig environment, there is clearly much more opportunity for the caretaker to spend time with individual pigs and forge a positive human–pig relationship. Indeed, depending on the purpose for which the pig is being kept, it may be essential that the caretaker spend many hours with each individual, not only for daily care and maintenance, but also training for specific procedures, such as dosing, blood draws, behavioural training, etc.

16.5.1 General concepts – positive/negative/minimal, individual recognition

The quality of human–animal interaction has significant impact on the animal's welfare (Tallet et al., Chapter 13: Pig-human interactions: Pig-human interactions: creating a positive perception of humans to ensure pig welfare). There is a large amount of research evidence to show that pigs subjected to negative handling show increased fear of humans and that this is reflected in the pigs' behaviour, physiology and production performance (see review by Spoolder and Waiblinger, 2009). Negatively handled pigs grow slower, have poorer reproductive performance, are more reluctant to approach humans and have increased plasma cortisol concentrations. In a laboratory setting, such responses would greatly impact the quality of the data being collected.

The amount of human–pig interaction needed to induce these effects is very small. For example, 30 seconds of negative handling a day can result in strong behavioural aversion towards humans (Hemsworth and Barnett, 1991). Also, being a pig within a group subject to negative handling is sufficient to induce the response in all individuals within the group (Hemsworth and Barnett, 1991). However, the converse is also the case – small amounts of positive handling can result in a reduction in fearfulness (Hemsworth et al., 1987), although inconsistency can be as adverse as negative handling alone (Hemsworth et al., 1987).

Many pigs used for laboratory studies may undergo repeated procedures that are painful or aversive, and thus, it could be argued that they will encounter inconsistency, in terms of the pig's perception of whether the interaction with the human is positive or negative. It may then be useful to know if the pig can compartmentalise the negative experiences and associate them with specific people or situations, leaving its more general interactions with its caretakers uninfluenced by the negative events (Tallet et al., Chapter 13: Pig-human interactions: Pig-human interactions: creating a positive perception of humans to ensure pig welfare). On farm, Hemsworth et al. (1994) found that pigs handled using either predominantly positive or negative interactions showed stimulus generalisation and were unable to distinguish between the handlers. However, where the amount of handling increased above that likely on commercial units, they did find that pigs could discriminate and would choose to interact more with a familiar handler over an unfamiliar handler (Hemsworth et al. 1996). Other studies have shown that pigs cannot only discriminate between individuals based on clothing colour (Koba and Tanida, 1999) but also use olfactory and visual cues (Koba and Tanida, 2001). Brajon et al. (2015a,b) have demonstrated that positive and negative handling can be remembered by the pig and will influence subsequent behaviour towards humans. However, importantly, experience of negative handling does not result in lasting aversion of humans: for example, pigs experiencing negative handling from handler B after a period of positive handling carried out by handler A, maintain a high motivation to explore and spend time with handler A (Brajon et al., 2015a). There may still be generalisation though, and the direction of this may be dependent on the behaviour of the handler. Those pigs that experienced both positive and negative handling generalised their positive experience when the handler was motionless (i.e., passive) but generalised their negative experience when the handler approached them (i.e. active).

Taken together, these results indicate that pigs can certainly discriminate between individual handlers and that negative interactions with one handler need not damage the relationship with other handlers. Aversive procedures can perhaps be assigned to a person other than the regular caretaker but it might also be that the presence of the regular caretaker during an aversive procedure may act as social support and reduce the pig's response to the procedure – i.e. that a strong positive human–pig relationship can improve the welfare of the pig. We do know that oxytocin is implicated in social bonding and we know that positive human contact results in a sustained increase in oxytocin measured in the cerebral spinal fluid of pigs (Rault, 2016). In other species, positive interactions with a human are sought by the animal (Bertenshaw and Rowlinson, 2008) and appear to elicit indicators of pleasure (Schulze Westerath et al., 2014). Thus, the possibility exists for a predictable, positive human–animal relationship to tangibly enhance the animal's welfare and perhaps provide a form of environmental enrichment (Claxton, 2011). This area could benefit from further study.

16.5.2 Training for procedures – weighing/blood sampling/dosing

Anyone who has worked with pigs is quickly aware that they are intelligent. The scientific literature shows that pigs are capable of learning and remembering complex tasks and anecdotal evidence of the pig's ability to assimilate information and use it to its own advantage is widespread, especially in the acquisition of food. Quantification of an animal's intelligence relative to other species is never simple, but judgement places the pig at the upper end of the scale, either just below companion animals such as the dog and cat (Davis and Cheeke, 1998) in the case of a survey of university faculty and students or, following a review of the literature,

Table 16.3 Representation of the four quadrants depicting options for methods of operant conditioning

	Reinforcement	**Punishment**
Positive (Stimulus added)	*Positive Reinforcement* Pleasant stimulus added to ⇧ desired behaviour	*Positive Punishment* Aversive stimulus added to ⇩ undesired behaviour
Negative (Stimulus removed)	*Negative Reinforcement* Aversive stimulus removed to ⇧ desired behaviour	*Negative Punishment* Pleasant stimulus removed to ⇩ undesired behaviour

with similar 'complex ethological traits' to dogs and chimpanzees (Marion and Colvin, 2015). This intelligence not only confirms that their environments should contain complexity (see above), but also means that they can be trained in order to make procedures within the laboratory setting less stressful for the pig and less stressful for the handler or caretaker. This intelligence and trainability applies equally to both the farm pig and the laboratory breeds (Murphy et al., 2013).

Within a laboratory setting, there may be several procedures that will become routine such as weighing, and restraint for dosing, either orally or via IM, IV or SC routes, and for blood sampling. Much of the aversive elements of these procedures can be reduced by subjecting the pig to operant conditioning using rewards and/or punishments. The most often used and recommended technique is that of positive reinforcement, whereby the pig is given a reward, usually a food reward, when the desired behaviour is carried out (e.g. Sørensen, 2010 – see Table 16.3).

The reward can be paired with a conditioned reinforcer, such as a clicker, to aid communication between pig and handler and act as a simple, unemotional cue (Arblaster, 2010). For a detailed description of training methods to help handling, dosing and sampling of laboratory pigs, an excellent resource is the Ellegaard Göttingen Minipigs educational package (Zeltner, 2013), which gives detailed coverage of training methods in relation to various common procedures. With sufficient time and consistency of interaction, pigs can be trained to be at ease during certain procedures (see Fig. 16.7).

In reality, positive reinforcement is often paired with negative punishment, in that an unwanted behaviour results in the removal of a pleasant stimulus. In this way, desired behaviour is rewarded and increased, while undesired behaviour is unrewarded and decreased, with the relationship between the animal and the handler largely maintained as positive. Use of negative reinforcement and positive punishment involves the handler applying aversive stimuli. Even though such techniques may result in the looked-for changes in behaviour, associating the handler with negative experiences can induce fear and distress. There is little scientific literature on the relative effectiveness of the different training methods with pigs, but work on other species, primarily dogs, indicates that positive punishment in particular can result in anxiety and increased probability of problem behaviours

Figure 16.7 Pig sitting and having blood sampled via multiple splanchnic vascular access ports.
Source: Helle Nygaard Lærke, Aarhus University.

(Hiby et al., 2004). However, Zeltner (2013) describes two situations in which positive punishment/negative reinforcement can be used to train minipigs to tolerate handling and being in a sling.

16.6 Management and alleviation of pain and discomfort

Even though the welfare of the large breeds of pigs kept as meat-producing animals has been subject of study for decades, the pig is among the least examined of the mammalian species held by man in terms of knowledge about pain (as reviewed in Herskin and Di Giminiani, Chapter 11: Pain in pigs: Characterisation, mechanisms and indicators). Considering that a large proportion of experimental pig studies involve tissue damage and potentially pain, this is a major challenge for the documentation of the animal welfare standard, which is needed in order to comply with the legal, ethical and scientific responsibilities of in vivo animal research.

As reviewed by Viñuela-Fernández et al. (2007), unmitigated pain is a major animal welfare concern, and unacceptable from a 3R perspective. Recently, Bradbury et al. (2016) reviewed biomedical literature and found that only remarkably few of the model studies involving porcine surgery reported whether and how the pain level of the animals were assessed. As no 'golden standard' for the presence of pain exists (Rutherford, 2002), what can be quantified and reported is indicators – measurements which give indication of the nature and severity of the pain experienced. The current knowledge about porcine indicators of pain have been reviewed by Herskin and Di Giminiani (Chapter 11: Pain in pigs: Characterisation, mechanisms and indicators). Below, we discuss examples considered especially relevant for pigs used for research purposes.

For the large proportion of laboratory pigs that undergo surgery or other types of tissue damage, the procedures (or the concurrent anaesthesia) may influence traditional physiological pain indicators. Hence, Flecknell (1994) recommended that documentation of pain states in laboratory animals focus on behavioural indicators, especially in cases involving postsurgical pain.

Across studies, feasibility of pain management benefits from assessment techniques characterised by high throughput. One such option, which can be done relatively quickly in pigs, might be the use of evoked behavioural responses, such as the quantification of avoidance responses to a standardised mechanical challenge (as for example described by Di Giminiani et al., 2013). Comparable methodology have been used in piglets (Fosse et al., 2011) or sows (Pairis-Garcia et al., 2015b) after experimentally induced inflammatory states mimicking conditions known from commercial pig production, as well as in studies modelling human pain (Castel et al., 2014; 2016). Swindle and Sistino (2015) described how responses to palpation as part of a clinical examination can be graded and used as part of the assessment of painful conditions in laboratory pigs. However, recently the clinical relevance of evoked behavioural responses has been debated in rodents, including a call for more ecologically relevant measures, for instance obtained by manipulation of the motivational states of the animals (e.g., Andrews et al., 2012). In pigs, Fosse et al. (2011) examined the motivation of piglets to pass a wooden ramp in order to get access to mother/siblings as a measure of the consequences of experimentally induced lameness.

In contrast to evoked behavioural responses (be it after standardised challenge or motivational tasks), quantification of the nonevoked animal behaviour is highly time consuming, but may provide important information about potential ongoing pain, which is critical as part of the required monitoring of laboratory animal welfare and may otherwise be missed. However, spontaneously-occurring behaviour has received almost no attention in porcine model studies relevant for pain. One suggested nonevoked behavioural indicator of pain in laboratory pigs is the latency to onset of feeding after surgery or another experimental procedure (Andersen et al., 1998; Malavesi et al., 2006). Future studies, preferably taking advantage of the knowledge from pigs kept for meat production, should focus on the validation of behavioural indicators of pain in pigs used for research in order to incorporate these measures into a welfare monitoring tool.

Despite the distinct lack of validated methodology to monitor and document pain in laboratory pigs, as well as lack of reporting of pain management (Bradbury et al., 2016), there are studies presenting effects of analgesic drugs, and their use is also recommended in textbooks on laboratory pigs (Swindle, 2015; Duedal Rölfing and Swindle 2015). Among examples of the studies are Pairis-Garcia et al. (2015a,b), documenting effects of an NSAID administered to sows in a transient lameness model. Reyes et al. (2002) examined postoperative pain relief in mini pigs following implantation of a central artery catheter via a inguinal incision, and used a multifactorial numerical rating scale inspired by rodent scales to show that the use of NSAIDs was able to normalise the pain scores. There are, however, also reports questioning the use of NSAIDs due to the possible insufficient analgesia when provided to animals in moderate to severe pain (Fish et al., 2008) as well as unwanted side effects that may alter research outcomes. In reference to such possible contraindication of NSAIDs in animal research, Royal et al. (2013) reviewed different alternatives for the alleviation of porcine pain relief. As part of a refinement study, the use of ultrasound guided regional anaesthesia in pigs in a femoral fracture model was tested and recommended.

Based on the current knowledge, pain monitoring of laboratory pigs should be done regularly, especially in the hours after surgery or other tissue damage. At present, no validated pain scales exist for pigs. Royal et al. (2013) presented a postoperative pain assessment method consisting of frequent observation of non-evoked behaviour (such as latency to eat and activity level), physiological indicators such as heart rate, combined with observations of evoked responses to palpation as well as actions by the caretaker to stimulate physical activity. Murison et al. (2009) reported another pain assessment procedure in laboratory pigs, which also included locomotion scoring and interaction with handlers. These authors specified that especially persistent sitting and reluctance to lie down were suggested as potential indicators of pain. Hence, even though no porcine pain scales have been formally validated, several suggested scales exist, including measures of evoked behavioural responses, non-evoked behaviour, clinical measures and to some extent physiological measures, and these may form the basis for future validation and adjustment of pain scales covering tissue damaging procedures common in studies involving pigs.

Beside pain, there are other negative affective states that may be experienced by pigs kept for research purposes. In this last part of the chapter, we will discuss two examples – consequences of the presurgical fasting and of the restraint needed to obtain tissue samples from laboratory pigs.

According to Swindle and Smith (2015) presurgical fasting of 8–12 hours will empty the stomach and small intestine, whereas colonic emptying usually requires fasting for 48–72 hours. During this period the welfare of the pigs is not only challenged by hunger (Lawrence and Illius, 1989; see also D'Eath et al., Chapter 7: Mitigating hunger in pregnant sows) but also by the lack of chewable objects, as pigs will attempt to eat any environmental enrichment (Swindle et al., 1994). In pigs kept for meat production, several studies have examined the welfare consequences of the fasting required before slaughter (e.g., Dalla Costa et al., 2016). However, effects of the required fasting on the welfare of laboratory pigs have not been examined systematically and warrants further study in order to refine the procedures as much as possible and to be able to offer substitute environmental enrichment, which may limit the effects of the withdrawal of food and eatable materials.

Interestingly, Swindle and Smith (2015) mention that agricultural methods of restraining pigs (e.g. by nose snare, which has been shown to lead to marked and sustained avoidance and stress responses) are inappropriate for laboratory pigs and provide examples of other restraining devices such as slings, the use of which are less severe for the welfare of the animals. In her paper 'Never wrestle with a pig....', Sørensen (2010) discussed how positive reinforcement training may be efficient in order to facilitate sampling of tissue from laboratory pigs and may improve animal welfare as well as the quality of research, thus emphasising the potential advantages from training and habituation of laboratory pigs before exposing them to experimental procedures.

16.7 Future trends and conclusions

Although numbers are difficult to quantify, it is likely that the popularity of the pig as a laboratory animal will continue to increase, and the potential applications of the pig will expand. At present, there is a paucity of scientific literature available on the laboratory pig with respect to welfare, although the rate of citations of those publications has increased greatly over the last few years (Fig. 16.8). This demonstrates a need for information that is not currently being met by papers specifically on laboratory pigs.

However, work undertaken in order to improve/secure welfare of laboratory pigs should keep in mind the existing knowledge about the pig as a meat producing animal including models involving tissue damage but aimed at, for instance, age-detection in forensic cases (e.g. Barington and Jensen, 2016). It is important to remember that a pig is a pig and that there is a great deal of useful information available on pigs as farm animals that can be directly applied to pigs as laboratory animals, be they farm pigs being kept for laboratory purposes or smaller purposebred pigs for laboratory use.

As the uses for pigs as laboratory animals increase, new welfare challenges may arise for which there is little current information. For example, the population of pigs kept for meat production may host many candidates for spontaneous animal

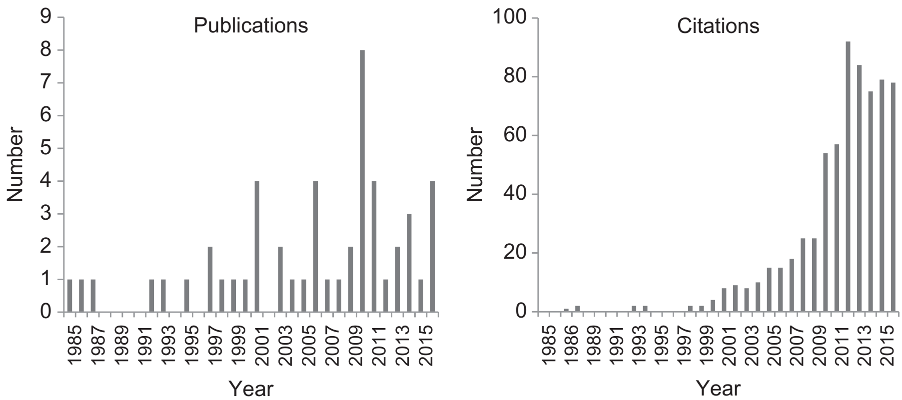

Figure 16.8 Number of publications and citations of studies that include search terms 'welfare' and 'laboratory pig', 'laboratory swine', 'miniature pig', 'miniature swine' or 'minipig' over the time period 1985–2016 (Web of Science).

models yet to be determined (Duncan et al., 2015) such as canine osteoarthritis models (Lascelles et al., 2009), and for which the welfare implications are unknown. The presence of such possibilities may also raise ethical debate in terms of whether it is more ethically acceptable to 'use' farm animal species for such experimentation rather than companion animal species, or less acceptable relative to rodents (e.g. Webster et al., 2010). However, this will also need to be balanced against the fact that the spontaneous models may be more biologically relevant compared to induced models and that the use of naturally spontaneous models better serves the 3 Rs (Russell and Burch, 1959).

Another major area which may see expansion of pigs kept for laboratory purposes is drug development for human medication. More and more researchers suggest that the pig may be part of the solution to some of the current translational problems. In drug development, it is estimated that only 1 in 10,000 potential drug molecules or new chemical entities (NCEs) make it to market. The vast majority of the drop-out is in the preclinical phase, which includes animal testing. However, even among compounds reaching clinical testing, only 10%–20% reach market, which means that the translation from 'successful' animal studies to human application is poor. Reasons for failure in the process may be multiple, but there does need to be greater scrutiny of the animal testing phase. The animal model needs to be applicable and relevant and there needs to be greater emphasis on both internal and external validity. The animal species used needs to be closely examined and the pig may well prove to be a good candidate species (Swindle et al., 2014). If so, even more research is needed in order to be able to monitor welfare and pain in these animals.

To conclude, it is important to keep in mind that 'the laboratory pig' covers several areas of research – from classical animal models for humans to porcine models for porcine conditions. Notwithstanding the purpose for which it is kept, the pig is an intelligent, social animal which is biologically programmed to perform a complex behavioural repertoire reminiscent of its ancestor, the wild boar. In order to maximise animal welfare, anyone taking care of the laboratory pig has the duty to acquaint themselves with the biology of the pig and best serve the needs of the pig within the constraints of the experimental protocol under which it is being kept.

Glossary

3 Rs the guiding principles for more ethical use of animals in testing which include replacement (methods which replace the use of animals), reduction (methods which reduce the number of animals used) and refinement (methods which refine animal welfare and reduce suffering)

NCE (new chemical entity) is a molecule developed in the early drug discovery stage, which after undergoing clinical trials could translate into a drug that could be a treatment for some disease

NSAID (non steroidal anti-inflammatory drug) a class of drugs that provide analgesic (pain-killing) and antipyretic (fever-reducing) effects, and, in higher doses, anti-inflammatory effects. Used in human (Aspirin, Ibuprofen, Paracetamol) as well as veterinary medicine.

References

Andersen, I.L., Bøe, K.E., 1999. Straw bedding or concrete floor for loose-housed pregnant sows: Consequences for aggression, production and physical health. Acta Agric. Scand. Sect. A. 49, 190–195.

Andersen, H.E.A., Fosse, R.T., Juiper, K.K.J., Nordrehaug, J.E., Pettersen, R.J., 1998. Ketorolac (Toradol ®) as an analgesic in swine following transluminal coronary angioplasty. Lab Anim. 32, 307–315.

Andrews, N., Legg, E., Lisak, D., Issop, Y., Richardson, D., Harper, S., Richardson, D., Huang, W., Burgess, G., Machin, I., Rice, A.S.C., 2012. Spontaneous burrowing behaviour in the rat is reduced by peripheral nerve injury or inflammation associated pain. Eur. J. Pain. 16, 485–495.

Arblaster, F., 2010. Clicker training in minipigs. Anim. Technol. Welf. 9, 115–118.

Baldwin, B.A., 1979. Operant studies on the behavior of pigs and sheep in relation to the physical environment. J. Anim. Sci. 49, 1125–1134.

Barington, K., Jensen, H.E., 2016. The impact of force on the timing of bruises evaluated in a porcine model. J. Forensic. Leg. Med. 40, 61–66.

Bertenshaw, C.E., Rowlinson, P., 2008. Exploring heifers' perception of 'positive' treatment through their motivation to pursue a retreated human. Anim. Welf. 17, 313–319.

Bollen, P.J.A., Hansen, A.K., Rasmussen, H.J., 2000. The Laboratory Swine. CRC Press, Boca Raton, FL.

Boyle, L.A., Regan, D., Leonard, F.C., Lynch, P.B., Brophy, P., 2000. The effect of mats on the welfare of sows and piglets in the farrowing house. Anim. Welf. 9, 39–48.

Bradbury, A.G., Eddleston, M., Clutton, R.E., 2016. Pain management in pigs undergoing experimental surgery; a literature review (2012-2014). Br. J. Anaesth. 116, 37–45.

Brajon, S., Laforest, J.-P., Bergeron, R., Tallet, C., Devillers, N., 2015a. The perception of humans by piglets: recognition of familiar handlers and generalization to unfamiliar humans. Anim. Cognit. 18, 1299–1316.

Brajon, S., Laforest, J.-P., Bergeron, R., Tallet, C., Hötzel, M.-J., Devillers, N., 2015b. Persistency of the piglet's reactivity to the handler following a previous positive or negative experience. Appl. Anim. Behav. Sci. 162, 9–19.

Broom, D.M., 2006. Behaviour and welfare in relation to pethology. Appl. Anim. Behav. Sci. 97, 73–83.

Casey, B., Abney, D., Skoumbordis, E., 2007. A playroom as a novel swine enrichment. Lab. Anim. (NY). 36, 32–34.

Castel, D., Willentz, E., Doron, O., Brenner, O., Meilin, S., 2014. Characterization of a porcine model of post-operative pain. Eur. J. Pain. 18, 496–505.

Castel, D., Naveh, M., Aharon, A., Doron, O., Meilin, S., 2016. Prolonged analgesic effect of PRF-108 and PRF-110 in postoperative pain in pigs. Pain Therapy. Available from: http://dx.doi.org/10.1007/s40122-015-0043-9.

Claxton, A.M., 2011. The potential of the human-animal relationship as an environmental enrichment for the welfare of zoo-housed animals. Appl. Anim. Behav. Sci. 133, 1–10.

Dalla Costa, F.A., Devillers, N., Paranhos da Costa, M.J.R., Faucitano, L., 2016. Effects of applying preslaughter feed withdrawal at the abattoir on behaviour, blood parameters and meat quality in pigs. Meat Sci. 119, 89–94.

Davis, S.L., Cheeke, P.R., 1998. Do domestic animals have minds and the ability to think? A provisional sample of opinions on the question. J. Anim. Sci. 76, 2072–2079.

D'Eath, R.B., Jarvis, S., Baxter, E.M., Houdijk, J., 2017. Mitigating hunger in pregnant sows. In: Špinka, M. (Ed.), Advances in Pig Welfare. Woodhead Publishing, Duxford, UK.

De Boer, S.F., Koolhaas, J.A., 2003. Defensive burying in rodents: ethology, neurobiology and psychopharmacology. Eur. J. Pharmacol. 463, 145–161.
DeBoer, S.P., Garner, J.P., McCain, R.R., Lay Jr., D.C., Eicher, S.D., Marchant-Forde, J.N., 2015. An initial investigation into the effects of social isolation and enrichment on the welfare of laboratory pigs housed in the PigTurn System assessed using tear staining, behaviour, physiology and haematology. Anim. Welf. 24, 15–27.
D'Eath, R.B., Turner, S.P., 2009. The natural behavior of the pig. In: Marchant-Forde, J.N. (Ed.), The Welfare of Pigs. Springer Science + Business Media B.V, Dordrecht, The Netherlands, pp. 13–46.
D'Eath, R.B., Tolkamp, B.J., Kyriazakis, I., Lawrence, A.B., 2009. 'Freedom from hunger' and preventing obesity: the animal welfare implications of reducing food quantity or quality. Anim. Behav. 77, 275–288.
DeBoer, S.P., Garner, J.P., Lay Jr., D.C., Eicher, S.D., Lucas, J.R., Marchant-Forde, J.N., 2013. Does the presence of a human effect the preference of enrichment items in young isolated pigs? Appl. Anim. Behav. Sci. 143, 96–103.
Di Giminiani, P., Petersen, L.J., Herskin, M.S., 2013. Nociceptive responses to thermal and mechanical stimulations in awake pigs. Eur. J. Pain 17, 638–648.
Di Giminiani, P., Petersen, L.J., Herskin, M.S., 2014. Characterization of nociceptive behavioural responses in the awake pig following UV-B-induced inflammation. Eur. J. Pain 18, 20–28.
Ducreux, E., Aloui, B., Robin, P., Dourmad, J.Y., Courboulay, V., Meunier-Salaun, M.C., 2002. Ambient temperature influences the choice made by pigs for certain types of floor. J. Rech. Porcine. 34, 211–216.
Duedal Rölfing, J.H., Swindle, M.M., 2015. Muscoskeletal system and orthopedic procedures. In: Swindle, M.M., Smith, A.C. (Eds.), 2015. Swine in the laboratory, third ed. CRC Press, Boca Raton, FL, pp. 317–336.
Duncan, J., Tinkey, P.T., Uthamanthil, R.K., 2015. Swine in cancer research. In: Swindle, M. M., Smith, A.C. (Eds.), 2015. Swine in the laboratory, third ed. CRC Press, Boca Raton, FL, pp. 465–488.
EFSA AHAW Panel (EFSA Panel on Animal Health and Welfare), 2014. Scientific opinion concerning a multifactorial approach on the use of animal and non-animal-based measures to assess the welfare of pigs. EFSA J. 12, 3702.
EU (European Union), 2016a. Commission Staff Working Document on best practices with a view to the prevention of routine tail-docking and the provision of enrichment materials to pigs. Available at: http://ec.europa.eu/food/animals/docs/aw-pract-farm-pigs-staff-working-document_en.pdf.
EU (European Union), 2016b. Commission Recommendation (EU) 2016/336 of 8 March 2016 on the application of Council Directive 2008/120/EC laying down minimum standards for the protection of pigs as regards measures to reduce the need for tail-docking. Offic. J. Eur. Union 59, L62/20-22.
Elmore, M.R.P., Garner, J.P., Johnson, A.K., Richert, B.T., Pajor, E.A., 2010. A flooring comparison: the impact of rubber mats on health, behavior and welfare of group-housed sows at breeding. Appl. Anim. Behav. Sci. 123, 7–15.
Ewald, C., Heer, A., Havenith, U., 1994. Factors associated with the occurrence of influenza A virus infections in fattening pigs. Berliner und Münchener tierärztliche Wochenschrift 107, 256–262.
Fish, R.E., Brown, M.J., Danneman, P.J., Karas, A.Z. (Eds.), 2008. Anesthesia and Analgesia in Laboratory Animals. Academic Press, San Diego (CA).

Flecknell, P.A., 1994. Advances in the assessment and alleviation of pain in laboratory and domestic animals. J. Vet. Anaesth. 21, 98–105.
Fosse, T.K., Toutain, P.L., Spadavecchia, C., Haga, H.A., Horsberg, T.E., Ranheim, B., 2011. Ketoprofen in piglets: enantioselective pharmacokinetics, pharmacodynamics and PK/PD modelling. J. Vet. Pharmacol. Therap. 34, 338–349.
Ganderup, N.-C., 2015. Use of swine in biomedical research. In: Swindle, M.M., Smith, A.C. (Eds.), 2015. Swine in the laboratory, third ed. CRC Press, Boca Raton, FL, pp. 523–537.
Gu, Z.B., Xin, H.W., Wang, C.Y., Shi, Z.X., Liu, Z.H., Yang, F.Y., Lin, B.Z., Wang, C., Li, B.M., 2010. Effects of neoprene mat on diarrhea, mortality and foreleg abrasion of pre-weaning piglets. Prev. Vet. Med. 95, 16–22.
Helke, K.L., 2015. Toxicology. In: Swindle, M.M., Smith, A.C. (Eds.), Swine in the Laboratory, third ed. CRC Press, Boca Raton, FL, pp. 419–441.
Hemsworth, P.H., Barnett, J.L., 1991. The effects of aversively handling pigs, either individually or in groups, on their behaviour, growth and corticosteroids. Appl. Anim. Behav. Sci. 30, 61–72.
Hemsworth, P.H., Barnett, J.L., Hansen, C., 1987. The influence of inconsistent handling by humans on behaviour, growth and corticosteroids of young pigs. Appl. Anim. Behav. Sci. 17, 245–252.
Hemsworth, P.H., Coleman, G.J., Cox, M., Barnett, J.L., 1994. Stimulus generalization: the inability of pigs to discriminate between humans on the basis of their previous handling experience. Appl. Anim. Behav. Sci. 40, 129–142.
Hemsworth, P.H., Verge, J., Coleman, G.J., 1996. Conditioned approach-avoidance responses to humans: the ability of pigs to associate feeding and aversive social experiences in the presence of humans with humans. Appl. Anim. Behav. Sci. 50, 71–82.
Herskin, M.S., Di Giminiani, P., 2017. Pain in pigs: characterisation, mechanisms and indicators. In: Špinka, M. (Ed.), Advances in Pig Welfare. Woodhead Publishing, Duxford, UK.
Herskin, M.S., Jensen, K.H., 2000. Effects of different degrees of social isolation on the behaviour of weaned piglets kept for experimental purposes. Anim. Welf. 9, 237–249.
Herskin, M.S., Hedemann, M.S., 2001. Effects of surgical catheterization and degree of isolation on the behavior and exocrine pancreatic secretion of newly weaned pigs. J. Anim. Sci. 79, 1179–1188.
Herskin, M.S., Bonde, M.K., Jorgensen, E., Jensen, K.H., 2011. Decubital shoulder ulcers in sows: a review of classification, pain and welfare consequences. Animal 5, 757–766.
Herskin, M.S., Jensen, H.E., Jespersen, A., Forkman, B., Jensen, M.B., Canibe, N., Pedersen, L.J., 2016. Impact of the amount of straw provided to pigs kept in intensive production conditions on the occurrence and severity of gastric ulceration at slaughter. Res. Vet. Sci. 104, 200–206.
Hiby, E.F., Rooney, N.J., Bradshaw, J.W.S., 2004. Dog training methods: their use, effectiveness and interaction with behavior and welfare. Anim. Welf. 13, 63–69.
Holtz, W., 2010. In: Hubrecht, R., Kirkwood, J. (Eds.), Pigs and minipigs, eighth ed. The UFAW Handbook on the Care and Management of Laboratory and Other Research Animals, UFAW, UK.
ILAR - Institute of Laboratory Animal Research, Committee for the Update of the Guide for the Care and Use of Laboratory Animals, National Research Council, 2011. Guide for the Care and Use of Laboratory Animals, eighth ed. National Academies Press, Washington, DC.
Ingram, D.L., 1965. Evaporative cooling in the pig. Nature 207: 415-416. Janssens CJJG, Helmond FA, Loyens LWS, Schouten WGP, Wiegant VM. 1995. Chronic stress

increases the opioid-mediated inhibition of the pituitary-adrenocortical response to acute stress in pigs. Endocrinology 136, 1468−1473.

Jensen, T.B., Toft, N., 2009. Causes of and predisposing risk factors for leg disorders in growing-finishing pigs. CAB Rev. Perspect. Agric. Vet. Sci. Nutr. Nat. Resourc. 4, 1−8.

Kanitz, E., Tuchscherer, M., Puppe, B., Tuchscherer, A., Stabenow, B., 2004. Consequences of repeated early isolation in domestic piglets (Sus scrofa) on their behavioural, neuroendocrine and immunological responses. Brain. Behav. Immun. 18, 35−45.

Kanitz, E., Puppe, B., Tuchscherer, M., Heberer, M., Viergutz, T., Tuchscherer, A., 2009. A single exposure to social isolation in domestic piglets activates behavioural arousal, neuroendocrine stress hormones and stress-related gene expression. Physiol. Behav. 98, 176−185.

Koba, Y., Tanida, H., 1999. How do miniature pigs discriminate between people: the effect of exchanging cues between a non-handler and their familiar handler on discrimination. Appl. Anim. Behav. Sci. 61, 239−252.

Koba, Y., Tanida, H., 2001. How do miniature pigs discriminate between people? Discrimination between people wearing coveralls of the same colour. Appl. Anim. Behav. Sci. 73, 45−58.

Laber, K.E., Whary, M.T., Bingel, S.A., Goodrich, J.A., Smith, A.C., Swindle, M.M., 2002. Biology and diseases of swine. In: Fox, J.G., Anderson, L.C., Loew, F.M., Quimby, F. W. (Eds.), Laboratory Animal Medicine, second ed. Academic Press, New York, pp. 612−675.

Lascelles, B.D.X., King, S., Roe, S., Marcellin-Little, D.J., Jones, S., 2009. Expression and activity of COX-1 and 2 and 5-LOX in joint tissues from dogs with naturally occurring coxofemoral joint osteoarthritis. J. Orthopaedic Res. 27, 1204−1208.

Lawrence, A.B., Illius, A.W., 1989. Methodology for measuring hunger and food needs using operant conditioning in the pig. Appl. Anim. Behav. Sci. 24, 273−285.

Lawrence, A.B., Newberry, R.C., Špinka, M., 2017. Positive welfare: what does it add to the debate over pig welfare? In: Špinka, M. (Ed.), Advances in Pig Welfare. Woodhead Publishing, Duxford, UK.

Lærke, H.N., Arent, S., Dalsgaard, S., Bach Knudsen, K.E., 2015. Effect of xylanases on ileal viscosity, intestinal fiber modification, and apparent ileal fiber and nutrient digestibility of rye and wheat in growing pigs. J. Anim. Sci. 93, 4323−4335.

Main, D.C.J., Whay, H.R., Leeb, C., Webster, A.J.F., 2007. Formal animal-based welfare assessment in UK certification schemes. Anim. Welf. 16, 233−236.

Malavesi, L.M., Nyman, G., Augustsson, H., Jacobson, M., Jensen-Waern, M., 2006. Effects of epidural morphine and transdermal fentanyl analgesia on physiology and behaviour after abdominal surgery in pigs. Lab. Anim. 40, 16−27.

Marchant-Forde, J.N., 2009. The welfare of dry sows. In: Marchant-Forde, J.N. (Ed.), The Welfare of Pigs. Springer Science + Business Media B.V, Dordrecht, The Netherlands, pp. 95−140.

Marchant-Forde, J.N., Marchant-Forde, R.M., 2005. Methods to reduce aggression at mixing in swine. Pig News Inf. 26, 63N−73N.

Marchant-Forde, J.N., Lay Jr., D.C., McMunn, K.A., Cheng, H.W., Pajor, E.A., Marchant-Forde, R.M., 2009. Post-natal piglet husbandry practices and well-being: The effects of alternative techniques delivered separately. J. Anim. Sci. 87, 1479−1492.

Marino, L., Colvin, C.M., 2015. Thinking pigs: A comparative review of cognition, emotion and personality in Sus domesticus. Int. J. Compar. Psychol. 28. Available at: http://escholarship.org/uc/item/8sx4s79c.

McCrackin, M.A., Swindle, M.M., 2015. Biology, handling, husbandry and anatomy. In: Swindle, M.M., Smith, A.C. (Eds.), 2015. Swine in the laboratory, third ed. CRC Press, Boca Raton, FL, pp. 1−38.

Mouttotou, N., Hatchell, F.M., Green, L.E., 1999. The prevalence and risk factors associated with forelimb skin abrasions and sole bruising in preweaning piglets. Prev. Vet. Med. 39, 231−245.

Muns, R., Malmkvist, J., Larsen, M.L.V., Sorensen, D., Pedersen, L.J., 2016a. High environmental temperature around farrowing induced heat stress in crated sows. J. Anim. Sci. 94, 377−384.

Muns, R., Nuntapaitoon, M., Tummaruk, P., 2016b. Non-infectious causes of pre-weaning mortality in piglets. Livestock Sci. 184, 46−57.

Murison, P.J., Jones, A., Mitchard, L., Burt, R., Birchall, M.A., 2009. Development of perioperative care for pigs undergoing laryngeal transplantation: a case series. Lab. Anim. 43, 338−343.

Murphy, E., Nordquist, R.E., van der Staay, F.J., 2013. Responses of conventional pigs and Göttingen miniature pigs in an active choice judgement bias task. Appl. Anim. Behav. Sci. 148, 64−76.

Mustonen, K., Banting, A., Raekallio, M., Heinonen, M., Peltoniemi, O.A.T., Vainio, O., 2012. Dose-response investigation of oral ketoprofen in pigs challenged with Escherichia coli endotoxin. Vet. Rec.. Available from: http://dx.doi.org/10.1136/vr.100431.

NRC (National Resesarch Council of the National Academies), 2012. Nutrient Requirements of Swine. 11th revised ed. The National Academies Press, Washington DC, USA, 420pp.

Navarro, R., Juhas, S., Keshavrzi, S., Juhasova, J., Motlik, J., Johe, K., Marsala, S., Scadeng, M., Lazar, P., Schulteis, G., Beattie, M., Ciacci, J.D., Marsala, M., 2012. Chronic spinal compression model in minipigs: a systematic behavioral, qualitative, and quantitative neuropathological study. J. Neurotrauma 29, 499−513.

Nevison, C.M., Hurst, J.L., Barnard, C.J., 1999. Strain-specific effects of cage enrichment in male laboratory mice (Mus musculus). Anim. Welf. 8, 361−379.

Newberry, R.C., 1995. Environmental enrichment: increasing the biological relevance of captive environments. Appl. Anim. Behav. Sci. 44, 229−243.

Nunoya, T., Kazumoto, S., Toshiki, S., Hajime, Y., Nakamura, K., Baba, Y., Hirai, T., 2007. Use of miniature pig for biomedical research, with reference to toxicologic studies. J. Toxicol. Pathol. 20, 125−132.

O'Driscoll, K., 2015. Visiting the FareWellDock meeting. Available at: <http://farewell-dock.eu/visiting-the-farewelldock-meeting-in-paris-april-8-2015/>.

Olsen, H.G., Kjelgaard-Hansen, M., Tveden-Nyborg, P., Birck, M.M., Hammelev, K.P., Vegge, A., Aalbßk, B., Jensen, H.E., Iburg, T., Heegaard, P.M.H., Nielsen, O.L., 2016. Modelling severe Staphylococcus aureus sepsis in conscious pigs: are implications for animal welfare justified? BMC Res. Notes. 9, 99.

Olsson IAS, Franco NH, Weary DM, Sandøe P., 2012. The 3R principle − mind the ethical gap! Proceedings of the ALTEX, WC8, pp. 333−336.

Pairis-Garcia, M.D., Johnson, A.K., Abell, C.A., Coetzee, J.F., Karriker, L.A., Millman, S.T., Stalder, K.J., 2015a. Measuring the efficacy of flunixin meglumine and meloxicam for lame sows using a GAITFour pressure mat and an embedded microcomputer-based force plate system. J. Anim. Sci. 93, 2100−2110.

Pairis-Garcia, M.D., Johnson, A.K., Stalder, K.J., Abell, C.A., Karriker, L.A., Coetzee, J.F., Millman, S.T., 2015b. Behavioural evaluation of analgesic efficacy for pain mitigation in lame sows. Anim. Welf. 24, 93–99.

Pedersen, L.J., 2017. Overview of commercial pig production systems and their main welfare challenges. In: Špinka, M. (Ed.), Advances in Pig Welfare. Woodhead Publishing, Duxford, UK.

Podgórski, T., Lusseau, D., Scandura, M., Sönnichsen, L., Jędrzejewska, B., 2014. Long-lasting, kin-directed female interactions in a spatially structured wildboar social network. PLoS. ONE. 9, e99875.

Poletto, R., Siegford, J.M., Steibel, J.P., Coussens, P.M., Zanella, A.J., 2006. Investigation of changes in global gene expression in the frontal cortex of early-weaned and socially isolated piglets using microarray and quantitative real-time RT-PCR. Brain. Res. 1068, 7–15.

Proudfoot, K., Habing, G., 2015. Social stress as a cause of diseases in farm animals: current knowledge and future directions. Vet. J. 206, 15–21.

Rault, J.L., 2012. Friends with benefits: social support and its relevance for farm animal welfare. Appl. Anim. Behav. Sci. 136, 1–14.

Rault, J.L., 2016. Effects of positive and negative human contacts and intranasal oxytocin on cerebrospinal fluid oxytocin. Psychoneuroendocrinlogy 69, 60–66.

Rehbinder, C., Baneux, P., Forbes, D., van Herck, H., Nicklas, W., Rugaya, Z., Winkler, G., 1998. FELASA recommendations for the health monitoring of breeding colonies and experimental units of cats, dogs and pigs. Report of FELASA working groups on animal health. Lab. Anim. 32, 1–17.

Reyes, L., Tinworth, K.D., Li, K.M., Yau, D.F., Waters, K.A., 2002. Observer blinded comparison of two non-opioid analgesics for postoperative pain in piglets. Pharmacol. Biochem. Behav. 73, 521–528.

Richter, S.H., Garner, J.P., Würbel, H., 2009. Environmental standardization: cure or cause of poor reproducibility in animal experiments? Nat. Methods 6, 257–261.

Richter, S.H., Garner, J.P., Auer, C., Kunert, J., Würbel, H., 2010. Systematic variation improves reproducibility of animal experiments? Nat. Methods 7, 167–168.

Roth, J.A., Tuggle, C.K., 2015. Livestock models in translational medicine. ILAR J. 56, 1–6.

Royal, J.M., Settle, T.L., Bodo, M., Lombardini, E., Kent, M.L., Upp, J., Rothwell, S.W., 2013. Assessment of postoperative analgesia after application of ultrasound-guided regional anesthesia for surgery in a swine femoral fracture model. J. Am. Assoc. Lab. Anim. Sci. 52, 265–276.

RSPCA., 2011. Pigs: Good Practice for Housing and Care. second ed. RSPCA, Research Animals Department, Horsham, UK.

Rusche, B., 2003. The 3Rs and animal welfare – conflict or the way forward? ALTEX. 20, 63–76.

Russell, W.M.S., Burch, R.L., 1959. The Principles of Humane Experimental Technique. Methuen, London.

Rutherford, K.M.D., 2002. Assessing pain in animals. Anim. Welf. 11, 31–53.

Sapkota, A., Marchant-Forde, J.N., Richer, B.T., Lay Jr., D.C., 2016. Including dietary fiber and resistant starch to increase satiety and reduce aggression in pregnant sows. J. Anim. Sci. 92, 2117–2127.

Savary, P., Gygax, L., Jungbluth, T., Wechsler, B., Hauser, R., 2011. A pilot study on the improvement of the lying area of finishing pigs by a soft lying mat. Berliner und Münchener tierärztliche Wochenschrift. 124, 17–21.

Schook, L., Beattie, C., Beever, J., Donovan, S., Jamison, R., Zuckermann, F., Niemi, S., Rothschild, M., Rutherford, M., Smith, D., 2005. Swine in biomedical research: creating the building blocks of animal models. Anim. Biotechnol. 16, 183–190.

Schulze Westerath, H., Gygax, L., Hillmann, E., 2014. Are special feed and being brushed judged as positive by calves? Appl. Anim. Behav. Sci. 156, 12–21.

Skoumbourdis, E.K., 2015. Pigs. In: Liss, C., Litwak, K., Tilford, D., Reinhardt, V. (Eds.), Comfortable Quarters for Laboratory Animals, tenth ed. Animal Welfare Institute, Washington, pp. 117–124.

Smith, M.E., Gopee, N.V., Ferguson, S.A., 2009. Preferences of minipigs for environmental enrichment objects. J. Am. Assoc. Lab. Anim. Sci. 48, 391–394.

Søndergaard, L.V., Herskin, M.S., 2012. Does size matter? Considerations of importance for choice of animal species in a transgenic model for Alzheimer's disease. In: Hagen, K., et al., (Eds.), Large Animals as Biomedical Models: Ethical, Societal. Legal and Biological Aspects, 51. Graue Reihe, pp. 84–100.

Søndergaard, L.V., Dagnæs-Hansen, F., Herskin, M.S., 2011. Welfare assessment in porcine biomedical research – suggestion for an operational tool. Res. Vet. Sci. 91, e1–e9.

Sørensen, D.B., 2010. Never wrestle with a pig.... Lab. Anim. 44, 159–161.

Spoolder, H.A.M., Waiblinger, S., 2009. Pigs and Humans. In: Marchant-Forde, J.N. (Ed.), The Welfare of Pigs. Springer Science + Business Media B.V, Dordrecht, The Netherlands, pp. 211–236.

Spoolder, H.A.M., Geudeke, M.J., Van der Peet-Schwering, C.M.C., Soede, N.M., 2009. Group housing of sows in early pregnancy: a review of success and risk factors. Livestock Sci. 125, 1–14.

Swindle, M.M., 2015. Pancreas and spleen. In: Swindle, M.M., Smith, A.C. (Eds.), 2015. Swine in the laboratory, third ed. CRC Press, Boca Raton, FL, pp. 155–169.

Swindle, M.M., Sistino, J.J., 2015. Anesthesia, analgesia, and perioperative care. In: Swindle, M.M., Smith, A.C. (Eds.), 2015. Swine in the laboratory, third ed. CRC Press, Boca Raton, FL, pp. 39–87.

Swindle, M.M., Smith, A.C. (Eds.), 2015. Swine in the laboratory, third ed. CRC Press, Boca Raton, FL.

Swindle, M.M., Smith, A.C., Laber-Laird, K., Dungan, L., 1994. Swine in biomedical research: management and models. Ilar. News 36, 1–5.

Swindle, M.M., Makin, A., Herron, A.J., Clubb Jr, F.J., Frazier, K.S., 2014. Swine as models in biomedical research and toxicology testing. Vet. Patholol. 49, 344–356.

Tallet, C., Brajon, C., Devillers, N., Lensink, J., 2017. Pig-human interactions: creating a positive perception of humans to ensure pig welfare. In: Špinka, M. (Ed.), Advances in Pig Welfare. Woodhead Publishing, Duxford, UK.

Telkanranta, H., Bracke, M.B.M., Valros, A., 2014. Fresh wood reduces tail and ear biting and increases exploratory behavior in finishing pigs. Appl. Anim. Behav. Sci. 161, 51–59.

Tuyttens, F.A.M., 2005. The importance of straw for pig and cattle welfare: a review. Appl. Anim. Behav. Sci. 92, 261–282.

Tuyttens, F.A.M., Wouters, F., Struelens, E., Sonck, B., Duchateau, L., 2008. Synthetic lying mats may improve lying comfort of gestating sows. Appl. Anim. Behav. Sci. 114, 76–85.

Valros, A., 2017. Tail biting. In: Špinka, M. (Ed.), Advances in Pig Welfare. Woodhead Publishing, Duxford, UK.

Van de Weerd, H.A., Docking, C.M., Day, J.E.L., Avery, P.J., Edwards, S.A., 2003. A systematic approach towards developing environmental enrichment for pigs. Appl. Anim. Behav. Sci. 84, 101–118.

Van de Weerd, H.A., Docking, C.M., Day, J.E.L., Edwards, S.A., 2005. The development of harmful social behaviour in pigs with intact tails and different enrichment backgrounds in two housing systems. Anim. Sci. 80, 289–298.

Vasdal, G., Mogedal, I., Bøe, K.E., Kirkden, R., Andersen, I.L., 2010. Piglet preference for infrared temperature and flooring. Appl. Anim. Behav. Sci. 122, 92–97.

Verdon, M., Hansen, C.F., Rault, J.L., Jongman, E., Hansen, L.U., Plush, K., Hemsworth, P. H., 2015. Effects of group housing on sow welfare: A review. J. Anim. Sci. 93, 1999–2017.

Verdon, M., Rault, J.L., 2017. Aggression in group housed sows and fattening pigs. In: Špinka, M. (Ed.), Advances in Pig Welfare. Woodhead Publishing, Duxford, UK.

Vinuela-Fernández, I., Jones, E., Welsh, E.M., Fleetwood-Walker, S.M., 2007. Pain mechanisms and their implication for the management of pain in farm and companion animals. Vet. J. 174, 227–239.

Webster, J., Bollen, P., Grimm, H., Jennings, M., 2010. Ethical implications of using the minipig in regulatory toxicology studies. J. Pharmacol. Toxicol. Methods. 62, 160–166.

Welfare Quality®, 2009. In: Forkman, B., Keeling, L. (Eds.), Assessment of animal welfare measures for sows, piglets and fattening pigs, Welfare Quality® Report No. 10, 310p.

Würbel H, Garner JP., 2007. Refinement of rodent research through environmental enrichment and systematic randomization. NC3Rs Invited article. Available at: <https://www.nc3rs.org.uk/sites/default/files/documents/Refinementenvironmentalenrichmentandsystematicrandomization.pdf>.

Zeltner A., 2013. Handling, dosing and training of the Gottingen minipig. Ellegaard Gottingen Minipigs A/S, Dalmose, Denmark. Available at: <http://minipigs.dk/fileadmin/filer/Education_package_New/Handling__Dosing___Training.pdf>.

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