Effects of group housing on sow productivity and welfare: review

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Executive Summary

Housing gestating sows in groups provides some obvious animal welfare advantages, although some sows may suffer from excessive aggression, injuries, stress and poor reproductive performance. This literature review, conducted by Australian and Danish scientists, examined factors affecting the welfare of sows in groups with the aim of identifying key research priorities to address risks to sow welfare and providing the Australian pork industry with information on how to successfully mix sows and manage them under group housing systems.

Floor space allowance markedly affects sow welfare. In addition to quantity of floor space, the quality of space is also important: spatial separation between sows can also be provided with visual or physical barriers and stalls. Thus optimizing factors such as floor space and other design features, such as barriers as well as providing access to resources such as feed, water and a lying area, appear to be important in reducing aggression and stress at mixing and beyond. While 1.4 m^2/sow is insufficient, further research is required to examine space effects in the range of 1.8-2.4 m^2/sow in more detail.

The period immediately post-mixing has the most pronounced effects on aggression and stress, and thus well-designed mixing pens offer the opportunity to reduce aggression, injury and stress while allowing the social hierarchy to quickly form before animals are moved to perhaps a less extensive group housing system for the remainder of gestation. Research is required to examine the effects of increased space in a mixing pen as well as the duration of housing in the mixing pen before floor space can be reduced without adverse effects. Sows in groups appear to quickly adapt to reduced space soon after mixing. The effects of other design features following the mixing pen, such as another feeding system or a dynamic group, on aggression and stress require examination.

Feeding system can affect aggression and stress, but the design of these systems in terms of stall length and ease of access to and from stalls, is likely to affect sow welfare. Since hunger is likely to lead to competition for feed or access to feeding areas, strategies to prolong satiety between meals through higher feeding levels, dietary fibre, other dietary ingredients or foraging substrate should be examined because of their implications on stereotypies and aggression.

Genetic selection on reduced aggression has the potential to reduce aggression and thus continued research on the opportunity to genetically select against aggressiveness and its broader implications is required.

Exposing juvenile gilts to sows (socialization) may facilitate more rapid and safe development of the social hierarchy in adulthood. The potential effects of early socialization on aggression, injuries and stress of sows mixed in later life require examination.

There are additional challenges when mixing sows at weaning and consequently a better understanding of mixing pen design is important in minimizing injury, stress and reproductive failure in these sows.

It is therefore recommended that the key research topics that should be the focus of a 3 to 5-year R&D investment and collaboration between Pork CRC and the Danish Pig Research Centre and the University of Copenhagen are:

1. Mixing pens
2. Socialization of juvenile gilts
3. Additional and alternative fibre in the diet and increased feeding levels in gestation
4. Access to a foraging substrate

As the Pork industry moves towards group housing of both gestating and weaned sows, understanding the design features of group housing that affect sow welfare and reproductive performance, through targeted R&D, is essential in protecting sow welfare and optimizing production efficiency.

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1. Introduction

On the basis of the popular press, one could be led to believe that the only welfare issues in relation to farm animal housing are stall (individual) housing of gestating sows, cage housing of laying hens and overcrowding of meat chickens. Another high profile welfare issue is the use of laboratory animals, although concerns are more over animal experimentation than housing and management issues. Australian and European surveys indicate that the public appear to be more concerned about the welfare of poultry and pigs than other farm animals (European Commission, 2007; Coleman, 2008), presumably because of restrictions in space, social contact and choice of stimuli for interaction associated with confinement of animals (Barnett *et al.*, 2001). Sectors of the general public are also increasingly questioning the welfare impact of and the need for some husbandry procedures, particularly surgical interventions that are likely to cause pain (Coleman, 2008).

These public concerns about housing in themselves raise a number of questions including the following: What is the best type of housing to provide and on what basis? Is outdoor housing better than indoor housing? What are the space allowance requirements of animals? What are the short- and long-term welfare consequences of restricted housing? What are the social requirements of animals and what type and amount of stimulation is desirable? Assuming we can determine the requirements of different species for space, social contact and environmental stimulation, what other facilities are required? While extensive production farming systems are generally not considered to involve 'housing', they do impose restrictions on animals, albeit with considerable freedom and there are different issues raised including frequency of inspections and opportunities to intervene when problems are encountered, climatic extremes and natural disasters such as fire, floods, drought and blizzards. Nevertheless, the main focus of welfare concerns by the public has been on intensive systems. While the major responses to these concerns have varied, a typical response has been the development of alternative systems, sometimes based on previous, more traditional practices such as large group, deep-litter systems for sows, as well as the development of more sophisticated indoor systems, such as electronic sow feeding (ESF) in pens. Often these systems have merely replaced one set of welfare problems with another and one reason for this substitution of welfare problems is that there is insufficient understanding of the animals' specific requirements in the alternative systems. For instance, Scott *et al.* (2007) studied some aspects of the health and welfare of finishing pigs housed in either fully-slatted or straw-based accommodation. The results highlight the relative health and welfare advantages and disadvantages of these two systems for finishing pigs. For example, lameness and tail-biting tended to be the more prevalent health conditions in the fully-slatted system, while in the straw-based system pigs showed more enteric and respiratory diseases. Pigs with straw spent a large proportion of their time manipulating it, while pigs without straw were less active and spent more time manipulating the pen features. Pigs with straw had more severe toe erosions, while pigs without straw had more severe heel erosions. Clearly as housing or husbandry systems are modified or replaced, research is necessary to identify welfare risks and their solutions. Furthermore, as commented by Barnett et al. (2001), while the physical design of the housing accommodation can have a marked impact on welfare, our knowledge of design from the perspective of welfare is often poor and thus, a better understanding of the important design features is likely to lead to improvements in welfare, in both new and present housing systems.

In relation to pork production, legislative, consumer, and retailer pressure on the pork industry has led to an increase the use of group housing of gestating sows. In 2010 the Australian pork industry agreed to voluntarily phase out gestation stalls for sows by 2017. However, international industry experience indicates that the opportunity for group housing to improve sow welfare can be limited by high levels of aggression that are commonly observed in newly formed groups of sows after mixing (Velarde, 2007). Sow aggression poses a significant risk to sow welfare and productivity. This aggression, especially if intense and prolonged, may lead to injuries, stress and consequently reduced welfare and reproductive performance. Although the problem of pig aggression has received considerable attention, detailed studies of aggressive behaviour have generally utilized staged paired encounters or small group sizes, with many studies using young immature pigs, rather than sows. Thus, there are few rigorous recommendations in the scientific literature on the design features of sow group housing that reduce aggression (Petherick and Blackshaw, 1987; Arey and Edwards, 1998; Barnett et al., 2001; Spoodler et al., 2009). Research on design features such as floor space allowance and feeding system is underway internationally but most of this research is examining these factors on grouping after insemination or particularly after confirmation of pregnancy.

A more thorough understanding of the effects of design features on grouping shortly after insemination on sow welfare and reproductive performance is clearly required. Furthermore, current knowledge on group housing from weaning is even more limited, particularly in terms of effects on sexual behaviour and consequently reproductive performance. With on-going community concern with confinement housing, the international pork industry is looking towards group housing of sows from weaning.

This project consists of two main components:

1) a joint review of the literature by Australian scientists and scientists of the Danish Pig Research Centre and the University of Copenhagen on the effects of group housing from both post-weaning and post-insemination on sow productivity and welfare; and
2) the identification of key research areas which would form a ‘road map’ for a 3 to 5-year R&D investment and potential collaboration between the Pork CRC and the Danish Pig Research Centre and the University of Copenhagen.

2. Methodology

Methods adopted

A joint review of the literature on the effects of group housing from both post-weaning and post-insemination on sow productivity and welfare was conducted, supervised by Prof Paul Hemsworth (The University of Melbourne) and Dr. Christian Hansen (University of Copenhagen) with the support of Ms. Megan Verdon, Dr Jean-Loup Rault and Ellen Jongman (The University of Melbourne), Ms. Lisbeth Hansen (Danish Pig Research Centre) and Ms. Kate Plush (University of Adelaide). This comprehensive review of the current international research covered published papers. Furthermore, Danish industry reports on commercially relevant work were also utilized in this review.

From this review key research areas were identified which were used to form a ‘road map’ for a 3 to 5-year R&D investment and collaboration on this topic between the Pork CRC and the Danish Pig Research Centre and the University of Copenhagen.

3. Outcomes

Research results

- Presented a comprehensive literature review (Appendix 1).
- Provided recommendations to the Pork CRC and the Danish Pig Research Centre and the University of Copenhagen on a 3-5 year R&D joint-investment and joint-collaboration on the effects of group housing both post-weaning and post-insemination on sow productivity and welfare. These are covered in detail in the Recommendations section (Chapter 7) of this Report.
- The scientific review of the effects of group housing both post-weaning and post-insemination on sow productivity and welfare will be submitted for publication in the Journal of Animal Science.
- A series of recommendations to industry have been prepared on the principles of grouping sows post-weaning and post-insemination to minimize welfare risks and maximise reproductive performance. These recommendations culminated with the joint APL/Pork CRC publication, *Mixing Sows-How to maximise welfare* edited by Ray King. This industry document was published in April 2014 and launched at the APL/Pork CRC Sow Housing Workshops at Toowoomba on 2 April and Melbourne on 4 April, 2014.

4. Application of Research

The literature review will be published in a scientific journal to provide an extensive and up to date review of the factors affecting the welfare of sows in groups. This review has been utilized to inform future research aimed towards optimizing the welfare of sows in groups. In particular, it is recommended that the focus of such research should be on:

1. Mixing pens
2. Socialization of juvenile gilts
3. Increased satiety and providing enrichment for dry sows, through:
    a. Additional fibre in the diet and increased feeding levels in gestation
    b. Access to a foraging substrate

The information collated from this review will also be presented to industry through industry publications and workshops, such the Pork CRC/APL Sow Housing workshops in April, 2014.

5. Conclusion

While group housing provides some obvious welfare advantages for sows, such as more freedom of movement, exploration and socialization, some animals may suffer from excessive aggression, stress and injuries. This literature review, conducted by Australian and Danish scientists, examined factors affecting the welfare of sows in groups with the aim of identifying key research priorities to address risks to sow welfare .

Floor space allowance markedly affects sow welfare. Pigs obviously have a requirement for physical space to stretch and exercise. Space may also be needed for body care or grooming and assisting in thermoregulation. In addition, pigs need to access key resources such as feed, water and lying space, and pigs are also motivated to interact with other sows and to explore, particularly if hungry. Thus they need space not only to access the resources but also if necessary to distance themselves from others, including when accessing these resources. In addition to quantity of floor space, the quality of space is also important: spatial separation between sows can also be provided with visual or physical barriers and stalls. Thus optimizing factors such as floor space and other design features, such as barriers as well as providing access to important resources such as feed, water and a lying area, appear to be important in reducing aggression and stress at mixing and beyond. While 1.4 m^2/sow is insufficient, further research should examine the effects of space allowance in the range of 1.8 to 2.4 m^2/sow in more detail.

The period immediately post-mixing has the most pronounced effects on aggression and stress, and thus well-designed mixing pens offer the opportunity to reduce aggression, injury and stress while allowing the social hierarchy to quickly form before animals are moved to perhaps a less extensive group housing system for the remainder of gestation. Research is required to examine the effects of increased space in a mixing pen as well as the duration of housing in the mixing pen before floor space can be reduced without adverse effects. The effects of other design features following the mixing pen, such as another feeding system or a dynamic group, on aggression and stress require examination.

As with space, feeding system can affect aggression and stress, but the design of these systems in terms of stall length and ease of access to and from stalls, is likely to affect sow welfare. Furthermore, since hunger is likely to lead to competition for feed or access to feeding areas, opportunities to prolong satiety between meals through higher feeding levels and provision of additional fibre in the diet or access to a foraging substrate should be examined because of their implications on stereotypies and aggression.

Genetic selection on reduced aggression has the potential to reduce aggression. Developments in understanding the opportunity to genetically select against aggressiveness and its broader implications on sow welfare and productivity should be closely followed and utilized if feasible and practical to minimize sow aggression.

Exposing juvenile gilts to sows (socialization) may facilitate more rapid and safe development of the social hierarchy in adulthood. The potential effects of early socialization on aggression, injuries and stress of sows mixed in later life require examination.

There are additional challenges when mixing sows at weaning and consequently a better understanding of mixing pen design, including flooring and protection of oestrous sows from mounting by others, as well as strategies such as those mentioned above (dietary and environmental manipulations), is important in minimizing injury, stress and reproductive failure in these sows.

It is therefore recommended that the key research topics that should be the focus of a 3 to 5-year R&D investment and collaboration between the Pork CRC and the Danish Pig Research Centre and the University of Copenhagen are:

1. Mixing pens
2. Socialization of juvenile gilts
3. Increased satiety and providing enrichment for dry sows, through:
    a. Additional fibre in the diet and increased feeding levels in gestation
    b. Access to a foraging substrate

As the Pork industry moves towards group housing of both gestating and weaned sows, understanding the design features of group housing that affect sow welfare and reproductive performance, through targeted R&D, is essential in protecting sow welfare and optimizing production efficiency.

6. Limitations/Risks

The following recommendations arise from a comprehensive review of the literature and are presented to assist the Pork CRC in developing and implementing its research priorities.

7. Recommendations

The main recommendations arising from this review of literature of the welfare and reproductive performance of sows in groups are as follows.

To reduce aggression, injuries and stress and maintain high reproductive performance in sows in groups, research is required on:

1. ***Mixing pens***. Specialized and dedicated pens for mixing unfamiliar sows offer the opportunity to reduce aggression, injury and stress while allowing the social hierarchy to quickly and safely form before animals are moved to a less extensive group housing system for the remainder of gestation.

   Features to address include:

   1. Mixing pen space allowance, and feeding stall and mating systems (e.g. insemination stall) design and their interactions.
   2. Provision of visual barriers in the pens.
   3. Provision of higher feeding levels and different dietary ingredients.

   Since there are additional challenges when mixing sows at weaning, this research on the important features of a mixing pen should utilize both weaned and recently-inseminated sows since there are likely to be some common principles applicable to both stages of reproduction that are necessary to minimize aggression, injuries and stress and maintain high reproductive performance. However, sexual behaviour displayed between weaning and oestrus may be an additional welfare concern in group-weaned systems, potentially leading to injuries and stress, which are not seen in sows kept in stalls and mixed after insemination.

   Furthermore, the effects of post-mixing pen space also requires investigation since a pen change and particularly a pen change with less space or the removal or introduction of animals in the group, may re-initiate aggression.

2. ***Socialization of juvenile gilts***. Based on limited research in other species, exposing juvenile gilts to sows (socialization) may facilitate more rapid and safer establishment of the social hierarchy when sows are mixed in adulthood. Thus research comparing mixing socialized sows with other unfamiliar socialized with mixing 'unsocialized' unfamiliar sows is warranted.
3. ***Additional fibre in the diet and increased feeding level post-insemination***. Hunger is likely to lead to competition for feed or access to feeding areas, and thus opportunities to prolong satiety between meals through higher feeding levels and provision of additional/different fibre or other ingredients in the diet should be examined because of their implications on stereotypies and aggression.
4. ***Increasing environmental complexity***. Strategies to increase environmental complexity and provide an outlet for exploratory behaviour may reduce the risk of the development of stereotypies. Thus effects of strategies to increase environmental complexity, such as a provision of a foraging substrate, should be examined in terms of both their long-term attractiveness to sows and the development of stereotypies.

Publish the review as a scientific paper.

The review should be submitted for publication in the Journal of Animal Science.

Prepare an industry publication.

The review should be utilized to prepare an industry publication that provides the key information for Australian pork producers to assist them in implementing strategies to reduce the welfare risk for their sows in group housing systems.

8. References

See Appendix 1

9. Appendix 1 – Literature review

THE EFFECTS OF GROUP HOUSING BOTH POST-WEANING AND POST-INSEMINATION ON SOW PRODUCTIVITY AND WELFARE

1. Introduction

On the basis of the popular press, one could be led to believe that the only welfare issues in relation to farm animal housing are stall (individual) housing of gestating sows, cage housing of laying hens and overcrowding of meat chickens. Another high profile welfare issue is the use of laboratory animals, although concerns are more over animal experimentation than housing and management issues. Australian and European surveys indicate that the public appear to be more concerned about the welfare of poultry and pigs than other farm animals (European Commission, 2007; Coleman, 2008), presumably because of restrictions in space, social contact and choice of stimuli for interaction associated with confinement of animals (Barnett *et al.*, 2001). Sectors of the general public are also increasingly questioning the welfare impact of and the need for some husbandry procedures, particularly surgical interventions that are likely to cause pain (Coleman, 2008).

These public concerns about housing in themselves raise a number of questions including the following: What is the best type of housing to provide and on what basis? Is outdoor housing better than indoor housing? What are the space allowance requirements of animals? What are the short- and long-term welfare consequences of restricted housing? What are the social requirements of animals and what type and amount of stimulation is desirable? Assuming we can determine the requirements of different species for space, social contact and environmental stimulation, what other facilities are required? While extensive production farming systems are generally not considered to involve 'housing', they do impose restrictions on animals, albeit with considerable freedom and there are different issues raised including frequency of inspections and opportunities to intervene when problems are encountered, climatic extremes and natural disasters such as fire, floods, drought and blizzards. Nevertheless, the main focus of welfare concerns by the public has been on intensive systems. While the major responses to these concerns have varied, a typical response has been the development of alternative systems, sometimes based on previous, more traditional practices such as large group, deep-litter systems for sows, as well as the development of more sophisticated indoor systems, such as electronic sow feeding (ESF) in pens. Often these systems have merely replaced one set of welfare problems with another and one reason for this substitution of welfare problems is that there is insufficient understanding of the animals' specific requirements in the alternative systems. For instance, Scott *et al.* (2007) studied some aspects of the health and welfare of finishing pigs housed in either fully-slatted or straw-based accommodation. The results highlight the relative health and welfare advantages and disadvantages of these two systems for finishing pigs. For example, lameness and tail-biting tended to be the more prevalent health conditions in the fully-slatted system, while in the straw-based system pigs showed more enteric and respiratory diseases. Pigs with straw spent a large proportion of their time manipulating it, while pigs without straw were less active and spent more time manipulating the pen features. Pigs with straw had more severe toe erosions, while pigs without straw had more severe heel erosions. Clearly as housing or husbandry systems are modified or replaced, research is necessary to identify welfare risks and their solutions. Furthermore, as commented by Barnett et al. (2001), while the physical design of the housing accommodation can have a marked impact on welfare, our knowledge of design from the perspective of welfare is often poor and thus, a better understanding of the important design features is likely to lead to improvements in welfare, in both new and present housing systems.

One of the reasons that housing of farm animals changed markedly post-second world war was because consumers and governments in western societies wanted cheap and safe food (Hodges, 2000). Science and the livestock industries responded and, consequently through improved housing and production methods, have increased productivity, improved the quality and lowered the cost of food. Furthermore, these changes in animal housing and production methods have reduced or eliminated a number of welfare problems such as predation, thermal stress, some infectious diseases and nutritional stress. However, these changes have exacerbated or created other welfare problems such as overcrowding, social restriction and lameness.

There appears to be increasing community concern with the treatment of animals (Fraser, 2008). Confinement housing of livestock, in particular the housing of gestating sows, appears to be at the forefront of these concerns, which in turn has led to legislative, consumer, and retailer pressure to increase the use of group housing of gestating sows. International industry experience, however, indicates that the opportunity for group housing to improve sow welfare can be limited by high levels of aggression that are commonly observed in newly formed groups of sows after mixing (Velarde, 2007). Sow aggression poses a significant risk to sow welfare and productivity. This aggression, especially if intense and prolonged, may lead to injuries, stress and consequently reduced welfare and reproductive performance. Although the problem of pig aggression has received considerable attention, detailed studies of aggressive behaviour have generally utilized staged paired encounters or small group sizes, with many studies using young immature pigs, rather than sows. Thus, there are few rigorous recommendations in the scientific literature on the design features of sow group housing that reduce aggression (Petherick and Blackshaw, 1987; Arey and Edwards, 1998; Barnett et al., 2001; Spoodler et al., 2009). Research on design features such as floor space allowance and feeding system is underway internationally but most of this research is examining these factors on grouping after insemination or particularly after confirmation of pregnancy.

A more thorough understanding of the effects of design features on grouping shortly after insemination on sow welfare and reproductive performance is clearly required. Furthermore, current knowledge on group housing from weaning is even more limited, particularly in terms of effects on sexual behaviour and consequently reproductive performance. With on-going community concern with confinement housing, the international pork industry is looking towards group housing of sows from weaning. This review of the literature considers the effects of group housing from both post-weaning and post-insemination on sow productivity and welfare.

Literature Review

2. Animal welfare

Animal welfare is a state within an animal (Mellor et al., 2009) and it concerns experienced sensations (Duncan, 2004; Mellor, 2012). For many scientists, animal welfare can be assessed on the basis of how well the animal is performing from a biological functioning perspective (Hemsworth and Coleman, 2011). For others, animal welfare concerns affective states (Duncan and Fraser, 1997), such as suffering, pain, and other negative feelings or emotions, as well as positive emotions such as pleasure, and animal welfare can be assessed on the basis of tests of preference and motivation. One concept in the literature is based on the view that the welfare of animals is improved in environments or situations in which the animals display normal or “natural” behaviour (Fraser, 2008). The so-called ‘five freedoms’, that is freedom from hunger and thirst, from discomfort, from pain, injury and disease, to express normal behaviour, and from fear and distress (FAWC, 1993) include aspects of all of these three concepts. While there is general agreement these freedoms are necessary to avoid a lack of suffering, there has been little attempt to both define the levels of freedom that are desirable and the adverse consequences of not providing such freedoms.

A review of the welfare methodologies and their rationale in assessing animal welfare has been done elsewhere (e.g. Broom and Johnson, 1993; Duncan and Fraser, 1997; Barnett and Hemsworth, 2009; Fraser, 2003, 2008; Hemsworth, 2013), but these three conceptual frameworks, biological functioning, affective states and normal or natural behaviour, will now be briefly reviewed.

2.1. Biological functioning

The rationale for this concept is that difficult or inadequate adaptation will generate welfare problems for animals (Hemsworth and Coleman, 2011). Broom (1986, 2000) defines the welfare of an animal as “its state as regards its attempts to cope with its environment”. The “state as regards attempts to cope” refers to first, how much has to be done in order to cope with the environment and includes biological responses such as the functioning of body repair systems, immunological defences, physiological stress responses and a variety of behavioural responses and second, the extent to which these coping attempts are succeeding, based on a lack of biological costs. These behavioural and physiological responses include abnormal behaviours, such as redirected and displacement behaviours and stereotypies, and the stress responses, such as activation of the sympathetic-adrenal-medullary and hypothalamic-pituitary-adrenal axes, respectively, while the success of the coping attempts are measured in terms of lack of biological costs, such as adverse effects on the animal's ability to grow, reproduce and remain healthy and injury-free (i.e., fitness effects).

The responses to stress are integral to the ability of an animal to cope and, in turn, the welfare of the animal. The behavioural and physiological adaptive responses are utilized by individuals to cope with challenges (Broom, 1986, 2000; Broom and Johnson, 1993; Moberg, 2000; Barnett, 2003). Marked challenges may overwhelm an individual’s capacity to adapt and lead to its death but while less severe challenges may not be fatal, they can still have significant biological costs, leading for example to impaired growth, reproduction and health, which in turn may result in welfare problems for the animal (Hemsworth and Coleman, 2011). It is the biological costs of stress that are therefore the means to appreciating the associated welfare implications (Moberg, 2000; Barnett, 2003). How well an animal can coping with its challenges will be indicated in the normality of its biological functioning, with severe risks to welfare associated with the most extreme coping attempts (Hemsworth and Coleman, 2011).

Although this concept of animal welfare has been criticized on the basis that it does not adequately include emotions, the mental state of an animal is a fundamental component of the animal’s biological state (Dantzer and Mormede, 1983). Emotional responses are produced in the limbic system, which projects to several parts of the brain, including those involved in the initiation and maintenance of the stress response, thus explaining why emotional insults activate a stress response (Panksepp, 2005; Kaltas and Chrousos, 2007).

Therefore, how well an animal is coping with its challenges will be indicated in the normality of its biological functioning, and extreme coping attempts will affect the fitness of the animal through a range of long-lasting behavioural and neuroendocrine responses.

2.2. Affective states

This concept defines animal welfare in terms of emotions and emphasizes reductions in negative emotions, such as pain, fear and nausea, and increases in positive emotions, such as comfort and pleasure (Duncan and Fraser, 1997). As indicated earlier, animal welfare ultimately concerns animal feelings or emotions. Since all living organisms have certain needs that have to be satisfied for the organism to survive, grow and reproduce, Duncan (2004) has argued that higher organisms (vertebrates and higher invertebrates) have evolved 'feelings' or emotions that provide more flexible means for motivating behaviour to meet these needs and consequently animal welfare concerns these feelings.

There are many definitions in the literature, but emotions are classically defined as an intense but short-lived affective response to an event, which is associated with specific body changes and thus is classically described through a behavioural component (a posture or an activity), an autonomic component (visceral and endocrine responses) and a subjective component (emotional experience or feeling) (Dantzer, 1988). Emotions in animals are cannot be measured directly and are difficult to measure indirectly (Duncan, 2005; Boissy et al., 2007), but there has been a substantial improvement in our knowledge of animal emotions in over the last two decades (Panksepp, 1998; Denton et al., 2009). There is no way to know if animals experience emotions similar to humans because of the nature of emotional self-experience (Boissy *et al.* (2007), but the behaviour, structure, and brain chemistry are similar in humans and in a large number of animal species. For example, other mammals are attracted to the same environmental rewards and drugs of abuse as humans; human emotions appear to be dependent on very similar sub-cortical brain systems; and artificial activations of these sub-cortical brain systems promote apparently positive and emotional responses, based on approach and avoidance measures (see reviews by Panksepp, 2005; Denton et al., 2009).

Although these emotional experiences of animals cannot be measured directly, there are behavioural, physiological and neurobiological indicators of emotion can be cautiously used (Murrell and Johnson, 2006; Mendl et al., 2010). Negative states such as fear and pain are often accompanied by activation of the sympathetic-adrenal-medullary and hypothalamic-pituitary-adrenal axes, however the relationships among behavioural response and neurobiological processes associated with other negative states such as frustration are less well understood. To date, most studies concerned with emotions have relied primarily on behavioural measures.

Tests of preference and motivation have been used to determine what resources or behaviours are important to an animal. While it seems likely that animals will avoid aversive stimulation and choose positive stimulation, preference and motivation testing have generated considerable debate relating to conceptual and methodological difficulties (see Nicol et al., 2009; Fraser and Nicol, 2011).

It is clear from this brief review that there is considerable commonality in the measurements used to study biological functioning and emotions.

2.3. Normal or natural behaviour concept

This conceptual framework promotes the principle that animals should be allowed to express their normal behaviour. For some this also implies that animals should be raised in ‘natural’ environments and allowed to behave in ‘natural’ ways.

Abnormal behaviour in domestic animals is frequently defined as behaviour that is either atypical for the species, outside the normal behavioural pattern that has evolved in the natural habitats of the species or outside the range usually observed in the species in non-captive situations (Keeling and Jensen, 2005). However, what are normal behaviours and natural environments for domestic animals is contentious (Appleby et al., 1992; Hemsworth and Coleman, 2011).

The view that animals should perform their full ‘repertoire’ of behaviour was very common in the early literature,, however there is broad agreement within science that it is often difficult to attribute actual suffering when the expression of certain behaviours is prevented or is absent when it would be expected to be present (Dawkins, 2003). Furthermore, as Fraser (2003, page 5) notes, “Few scientists today would support the simple view that animal welfare depends on the animal carrying out all its natural behaviour in a natural environment because natural environments contain many hardships (harsh weather, predators), and natural behaviour includes many means of dealing with hardship (shivering, fleeing).”

Thus the concept of ‘natural’ would need to be more specific before it could give guidance in assessing animal welfare, since generalizations may lead us astray and achieve the opposite of what is intended. Similarly, the ‘natural behaviours’ that are desirable or undesirable in terms of animal welfare require definition together with the rationale for their inclusion or exclusion. More recently the emphasis has been on behavioural indicators of poor coping such as fearfulness, aggression and stereotypies (EFSA, 2005), responses that are also utilized in the biological functioning concept of animal welfare.

Related to this notion of the importance of normal behaviour is that of 'behavioural (or ethological) need' (Hemsworth, 2013). It appears that this term 'behavioural need' was introduced into the scientific literature without any scientific evidence (Duncan, 1998). Dawkins (1990) and Fraser and Duncan (1998) suggested that the term 'behavioural need' refers to situations that elicit intense negative emotions and likely evolved for those behaviours in which an immediate action is necessary to cope with a threat to survival (e.g., escape from a predator) or reproductive fitness (e.g., nesting). In contrast, other types of behaviour that can be performed when the opportunity arises (e.g., play, grooming) are more likely to be associated with positive emotional states. Duncan (1998) defined “behavioural needs” as behaviour patterns that are very strongly motivated, and, if they are not allowed expression, the animal’s welfare may be jeopardized. However, as noted by several authors (e.g., Duncan, 2005; Cooper and Albentosa, 2003), any argument for impaired welfare due to restriction of these behaviours would be strengthened by supporting evidence of decreased health or increased physiological stress.

2.4. Conclusions on welfare assessment

The assessment of animal welfare requires the use of multiple indicators from multiple disciplines but the quantification of the relative importance of these indicators is lacking (Barnett et al., 2001; Fraser, 2008; Nicol et al., 2011). Basically scientists have used two main concepts in studying animal welfare, biological functioning and affective states, and these studies require the disciplines of animal behaviour, immunology, neurophysiology, psychology, stress physiology, and veterinary science.

The two conceptual frameworks, biological functioning and affective states, were initially seen as competing, however a more unified view amongst scientists has now emerged where biological functioning is viewed to include emotions and emotions are regarded as products of biological functioning (Boissy et al. 2007; Barnett and Hemsworth 2009; Mellor 2012). Furthermore, rather than relying on one concept, any argument for impaired welfare due to restriction of a resource or behaviour would be strengthened by evidence of both high motivation to access the resource or perform the behaviour, respectively, and disruption to biological function, such as occurrence of abnormal behaviour, increased stress and poor health.

Although definitions, and thus approaches to assessing animal welfare vary in the literature (Fraser, 2008, Barnett and Hemsworth, 2009), a broad approach, measuring behavioural, physiological and health and fitness responses to assess biological functioning as well as preference or motivation are used in this review in assessing animal welfare implications.

3. Relevant indices of sow welfare

3.1. Aggression

Livestock are social animals, and the housing environments in current production systems generally allow for frequent interactions among conspecifics (Maple, 1975). Agonistic behaviour is one form of social behaviour which is unavoidable and thus occurs during interactions between sows. Scott and Fredericson (1951) define agonistic behaviour as 'the group of behavioural adjustments associated with fighting, which includes attack, escape, threat, defense, and appeasement'.

Agonistic behaviour is generally studied by measuring aggression (fight) or flight in the receiver (Jensen, 1982). Aggressive interactions are generally considered to include the following behaviours (Jensen 1980, 1982; Mendl et al., 1992): knock by the head (head-to-head/head-to-body knock); bite (to any part of another pig); threaten (with open mouth lunges at another pig); chase; and fight (two pigs engage in knocking, biting, 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: retreat (pig moves rapidly away from another pig that is delivering aggression); and avoid (pig moves rapidly away from another pig that is not directing any behaviour at it).

Aggression is rare within groups of wild sows or even domestic pigs released in semi-natural conditions. The basic social unit in the wild is a stable cohort of 2–6 related females, with associated juvenile and sub-adult offspring (Stolba, 1989; Mauget, 1991; Gabor et al., 1999). The groups do not have territories but may have overlapping home ranges without conflict. However, pigs show aggression to unfamiliar pigs (Zayan, 1990). The fact that aggression is rare within groups of wild sows is in part due to the regulation of a stable dominance hierarchy (Jensen, 1982). The term 'dominance' refers to the predictable relationship between a pair of conspecifics, where one has learnt to dominate the other animal (subordinate), which in turn tends to avoid the confrontations between the two (Lindberg, 2001). Once established, the dominance hierarchy or 'avoidance order' functions to reduce the need for aggression and consequently injury, since subordinate sows actively avoid conflict with dominant sows (Jensen, 1982).

Thus the dominance hierarchy regulates the priority access to resources within the group without the need for aggression or at least reduced aggression. The formation of the dominance hierarchy is an important mechanism that functions to control aggression in situations of limited resources, such as space and feed. When two groups of unfamiliar wild sows meet intense agonistic behaviour is observed as a new dominance relationship is formed (Gabor et al., 1999), a social motivation which remains in the domesticated pig. While design features of the group-housing system are influential, aggression is often reported to peak approximately 2 h after mixing in commercial settings, and decrease significantly thereafter as a hierarchy is formed (Meese and Ewbank, 1973; Barnett et al., 1992;; Kay et al., 1999; Durrell et al., 2002; Marchant-Forde, 2009. Arey (1999) found that skin lesion scores in sows fell rapidly 3 days after mixing and remained constant after 1 week. The rate of decline of aggression is likely to be affected by access to resources such as space, feed, water and lying area.

Meese and Ewbank (1973) observed the aggressive behaviour of young pigs in groups of eight and found that the peak in aggression after mixing was almost entirely attributed to the animals that later became dominant. Similarly, Arey (1999) found that when unfamiliar sows were mixed, 61% of fights at mixing involved the sow that subsequently became the most dominant. Mount and Seabrook (1993) found no relationship between aggression delivered and that received after mixing, possibly because aggressive sows engage in fights while still delivering to those subordinate to them (Verdon et al., 2012). These findings suggest that the intense period of aggression after mixing is largely due to aggressive sows fighting to stake a claim for dominance and as such, it may be misleading to conclude that welfare is compromised in these animals. This is not to say that their welfare is not compromised during mixing, rather that the benefits of a reduced risk of receiving aggression later in gestation outweighs the cost of receiving significant aggression at mixing, if the sows successfully achieve dominance. Indeed sows that are classified as dominant on the day after mixing have been shown to receive less aggression later in gestation (Verdon et al., 2013).

Another consideration is how the nature of agonistic behaviour changes once a hierarchy has been achieved. Meese and Ewbank (1973) reported that in young pigs, fighting ceases within 24 h after mixing and by 48 h a social order is achieved. Similarly, in dry sows Krauss and Hoy (2011) found that the number of agonistic interactions significantly reduced after 24 h. This reduction may in part be due to a change in the nature of aggression from mostly reciprocal fighting at mixing, to the less severe head knocks and single bites (Karlen et al., 2007). Aggression has been reported to reach baseline levels within 1-2 days post-mixing (Marchant-Forde, 2009), with no further reductions from day 2 to day 4 post-mixing (Krauss and Hoy, 2011). Discrepancies between studies may in part be due to variations in environmental factors (e.g. pen design, space allowance, group size, group composition etc.), which are discussed later in the review. In addition, studies of social cohesion have found that when new sows are introduced to stable resident groups, it takes between 14 and 21 days for the new group to socially integrate into the resident group (Moore et al., 1993; Krauss and Hoy, 2011). Due to the 'avoidance order', sows that are successful in achieving a dominant position have a reduced need to subsequently display aggression (Broom and Fraser, 2007; Gonyou, 2001). Thus reduced aggression may be a useful indication that an avoidance order is functioning. Therefore, aggressive behaviour most accurately reflects an operating hierarchy between 24 h post-mixing and before the 'avoidance order' is functioning to regulate the hierarchy.

While bouts of aggression associated with the formation of a hierarchy is intense, it may also be short-lived. In comparison, aggression once a hierarchy has been formed, which occurs mostly over competition for a restricted resource, such as food, is shorter in duration but occurs much more frequently (Spoolder et al., 2009). Thus, while the welfare of dominant sows may be poor in the hours immediately after mixing, the welfare of those sows that fail to achieve a dominant position after mixing and continue to receive aggression throughout gestation may be compromised over a longer period, especially if sows are competing for feed or access to a feeding area. Additionally, frustration associated with, for example, an unpredictable environment or food restriction, may lead to a higher incidence of aggression (Carlstead, 1986; Broom and Johnson, 1993). Thus the welfare of those sows that consistently deliver aggression, regardless of how much they receive, may also be compromised.

Although welfare is defined in terms of the individual, it is often assessed at a group level, for example total aggression or mean level per sow. Individual variation in the aggressive behaviour of pigs has been well documented (Hansen et al., 1982; Mount and Seabrook, 1993; Mendl et al., 1992; Ruis et al., 2002; D'Eath et al., 2009; Turner et al., 2009; Verdon and Hemsworth, 2011; Verdon et al., 2012). More recently, aggressive behaviour on the day after mixing (Verdon and Hemsworth, 2011) and agonistic behaviours for 3 days or 3 weeks (Mendl et al., 1992; Zanella et al., 1998) following mixing have been used to classify sows as dominant (those that deliver more aggression/displace more sows than they received/were displaced), subdominant (those that received more aggression/were displaced more than they delivered/displaced others), or submissive (those the delivered no aggression/displaced no sows). There is agreement between studies that classification early after mixing is related to how the sow performed throughout gestation in terms of adrenal activity, weight gain, injuries and reproductive performance (Mendl et al., 1992; Verdon and Hemsworth, 2012; Verdon et al., 2013). However, while dominant sows performed best in each of these studies, it was harder to determine whose welfare was more compromised between the subdominant and submissive classifications. Therefore, classifying sows based on individual aggression delivered, while accounting for individual aggression received, may provide a good indication as to hierarchical position, which is related to sow welfare later in gestation.

Observations on aggressive behaviour are time consuming and continuous observations are necessary rather than instantaneous or point sampling at pre-determined time points. Many of the aggressive interactions are events (behaviours of very short duration) rather that states (behaviours of appreciable duration) and consequently require continuous observations to provide accurate information (Martin and Bateson, 2009).

The occurrence of aggression has been associated with a number of well-accepted welfare indictors, including skin lesions (Turner et al., 2009; Brown et al., 2009; Arey, 1999), cortisol concentrations (Barnett et al., 1992, 1993; Barnett, 1997) and immune function (Barnett et al., 1992, 1993; Barnett, 1997; D'Eath et al., 2002).

3.2. Injuries and lameness

Lameness is common in the swine industry, and is considered major welfare concern that has the potential to induce pain and discomfort for extended periods of time (Main et al., 2000; Barnett et al., 2001) and is widely considered as an animal-based indicator of poor welfare (Barnett et al., 2001; Barnett and Hemsworth, 2009). First and foremost, injuries are painful, and are therefore associated with some level of suffering in the animal (Dawkins, 1998). Similarly, the primary cause of lameness is pain (Cockram and Hughes, 2011; Fraser and Broom, 1990).

Skin lesions, such as scratches or cuts, are the most common injury sustained by group-housed sows, although the vulva is also an occasional target (EFSA, 2007; Chapinal et al., 2010). In addition to being painful, lesions expose the animal to infection (Smulders et al., 2006), and have been related to increased adrenal activity (in pigs: D'eath et al., 2012; Couret et al., 2009; in sheep: Ley et al., 1992, 1994) and reduced condition (Spoolder et al., 1997; Boyle et al., 1999). Skin lesions can also be considered as an indicator of poor welfare when numbers are high in individuals because skin lesions are often a consequence of aggression (Turner, 2006a,b).

Lameness, which is loosely defined as impaired movement or deviation from normal gait (Cockram and Hughes, 2011), is also common in commercial sows (Chapinal et al., 2010; de Koning, 1987). The causes of lameness range from inflammation and pain (Cockram and Hughes, 2011) and infected skin and claw lesions (Verlade, 2007), to broken bones (Marchant-Forde, 2009). However, in comparison to skin lesions, the consequences associated with lameness can be very serious. The USDA has ranked lameness as the third most common reason for culling sows on farm (15% of sows; USDA, 2001, 2007) and Stalder et al. (2004) reported that leg soundness was one of the most commonly identified reasons for the involuntary culling of sows.

When assessing injuries, it is common for the areas of the pig to be divided into sections of the body, for example the head and neck, the flank and back, and the hindquarters (Verlade, 2007). This simplifies the scoring process, identifies the source of the lesion, and reduces error due to double counted scores. There are two main methods used to assess injuries. The first involves ranking lesions on a scale. This can be done on the basis of lesion frequency (Moore et al., 1994; Hodgkiss et al., 1998; Arey, 1999; O'Connell et al., 2003; Séguin et al., 2005; Tönephöhl et al. 2013), severity (Geverink et al., 1996; Zurbrigg and Blackwell, 2006), or a combination of both (Anil et al., 2005; Schneider et al., 2007; Strawford et al., 2008; Stukenborg et al, 2011). Alternatively, the frequency of lesions can be counted (Turner et al., 2006a, 2006b, 2008; D'Eath et al., 2010). Accounting for the type and age of the lesion while counting them (Karlen et al., 2007; Verdon et al., 2011, 2012; Hemsworth et al., 2013) allows for both total and fresh lesions to be recorded, which is particularly useful in identifying sows whose welfare is at risk from both, or either, long-term injuries or continuing aggression.

While ranking lesions simplifies the scoring process and reduces inter-observer variability, animal variation is reduced. For example, if a pig has greater than 5 (Anil et al., 2005) or 10 (Séguin et al., 2005) injuries in a body section, that section is assigned the highest injury ranking. However, the range of injuries counted on growing pigs varied from 0-337 (Turner et al., 2006b). According to Broom (1991), the welfare of an animal with one injury is poorer than an animal with no injuries, so one would expect that the welfare of a pig with 337 injuries would be poorer than one with, for example, 100 injuries. Thus, by ranking injuries the effects of the most severely injured animals could be overlooked.

Lameness can most easily be detected through direct observation of gait abnormalities (Verlarde, 2007). This can be done by ranking sow locomotion on a scale and various scales have been utilized (Karlen et al., 2007; Schneider et al., 2007; Sasaki et al., 2009; Valros et al., 2009; Anil et al., 2009). While increasing the ways in which a sow could be ranked captures more animal variation, it may also increase the chance of human error and Fraser and Broom (1990) recommend that animals be singled out and observed in good lighting moving on a clean, dry and level surface for lameness to be accurately scored. Furthermore Karlen et al. (2007) recommend that sows should be walked at least 30m prior to assessment to avoid confusion between lameness and stiffness (Karlen et al., 2007). Behavioural observations, such as standing, lying and exploratory behaviours (Bonde et al., 2004; Valros et al., 2009; Main et al., 2010) and posture (Barnett and Hemsworth, 1988) have also been used to quantify lameness.

Lesions are used as a proxy measurement for aggression because they are considered to be visual evidence that a sow has received aggression (Turner et al., 2006a, 2006b, 2008; Schenider et al., 2007; Spoolder et al., 2009; Chapinal et al., 2010; D'Eath et al., 2010; Stukenborg et al., 2011). As with aggression, the frequency of skin lesions peaks after mixing, declining thereafter (Arey, 1999; Anil et al., 2005; Séguin et al., 2005), and variations in lesions sustained by individual sows are associated to variations in aggressiveness (Barnett et al., 1992, 1993; Moore et al., 1994; Geverink et al., 1996; Arey and Edwards, 1998; Turner et al., 2006a;; Verdon et al., 2012;). However, like aggression, when using injuries to assess welfare both the time after mixing and the social status of the sow needs to be considered.

Turner et al. (2006a) found that the total numbers of lesions 24 h after mixing were related to the amount of time a pig spent in reciprocal aggression (fighting) and the amount of time spent being bullied. Thus pigs that avoid aggression after mixing could be identified by their low levels of injuries. In a later study, Turner et al. (2009) found lesion frequency in finishing pigs 24 hours post-mixing was positively correlated with lesion frequency 3 weeks later, indicating that post-mixing lesions are predictive of those sustained under more stable conditions. In contrast to these studies on young pigs, dominant sows may have a high number of lesions early after mixing but reduced lesions in the long term (O'Connell et al., 2003; Arey, 1999; Verdon et al., 2012). Although Verdon et al. (2013) found no difference in the number of injuries sustained by dominant, subdominant and submissive sows on the day after mixing, on days 9 and 51 post-mixing lesions in dominant sows were significantly less than in sub-dominant sows, with submissive sows having the most. Distinguishing between pigs that sustain injuries during fights and those that do so while being bullied after-mixing is difficult when using lesion scores alone (Turner et al., 2006a). Lesion location may indicate how an injury occurred. In general, aggression associated with reciprocal fighting is directed to the front third of the body, while injury associated with being bullied is concentrated on the anterior, although there is considerable error associated with this (Turner et al., 2006a). Thus, as was found for aggression, the welfare of a dominant sow may be poor after mixing, but the welfare of submissive sows may be compromised over a longer period, in terms of injuries.

3.3. Stress

Responses to stress are integral to the ability of an animal to cope and, in turn, the welfare of the animal. A stress response commences once the central nervous system firstly perceives a potential challenge (stressor) to homeostasis and secondly develops a biological response or defence that consists of some combination of the four general biological defence responses: behavioural responses, responses of the autonomic nervous system, responses of neuroendocrine systems and responses of the immune system. For many stressors, the first and, at times, the most biologically economical and effective response is a behavioural one. In concert with the behavioural responses, the physiological responses that can be used by the animal are elicited basically in three series of events, with the full elicitation of these dependent on the time of exposure to the stressor and the success of the biological responses in coping with the challenge. Two key physiological responses that involve both neural and hormonal systems are the activation of the sympathetic-adrenal-medullary (SAM) followed by the activation of the hypothalamic-pituitary-adrenal (HPA) axes. Together, the responses of the SAM and HPA axes result in what is commonly termed the stress response, which encompasses one of the body's major coping mechanisms to environmental disturbance. The ability of the body to cope can be compromised if these systems respond inadequately or if there is excessive and prolonged activation of these systems. The latter is more common than the former.

The SAM axis response is the first series of physiological events and is characterized by a rapid, specific response of the autonomic nervous system and consequent release of the catecholamine noradrenaline (norepinephrine) from postganglionic nerve terminals and the secretion of noradrenaline and another catecholamine, adrenaline (epinephrine) from the adrenal medulla. These physiological adjustments are the immediate or 'emergency' response proposed by Walter Cannon (Cannon, 1914) as the 'fight or flight' response. The predominant actions of the catecholamines are to stimulate rapid and vigorous neural, behavioural and muscular activity, to stimulate the cardiovascular system to increase cardiac output and redistribute blood flow to the pulmonary system and appropriate organs to deal with the stressor (Goldstein and Grossman, 1987) and to quickly provide energy in the form of glucose from liver and muscle glycogen, a process known as glycogenolysis, and free fatty acids from lipolysis of adipose tissue (Murray *et al.*, 2003). Thus the SAM axis response is the principal regulatory mechanism that allows the animal to immediately meet physical or emotional challenges of a stressor.

Whereas the SAM is activated immediately upon detection of a stressor, and the response is transient, the HPA axis is activated less rapidly and the response is more prolonged. The consequent of activation of the HPA axis is the secretion of corticosteroid hormones from the adrenal glands. There are two predominant corticosteroids; cortisol is the predominant corticosteroid of most mammals, including humans, and bony fish, and corticosterone is the major corticosteroid in rodents, birds, reptiles, amphibians and cartilaginous fish (Chester Jones and Henderson, 1976).

The initial activation of the HPA axis, called the acute stress response (Selye, 1946; 1976), is a corticosteroid-dependent mechanism. The adrenal cortex and in particular the cortical cells that secrete the corticosteroids are controlled by higher centres of the hormonal system, the anterior pituitary gland, which in turn is controlled by the hypothalamus of the brain. The acute response may last from minutes to hours and has the major function of providing glucose from food or muscle protein (gluconeogenesis) for the required increased metabolic performance. Therefore, during this stage a steady state is achieved in which the increased demand for energy is met by increased metabolic performance. This physiological state of stress disappears on removal of the stressor with generally no ill effects other than a depletion of energy reserves.

The activation of the SAM and HPA axes is obviously an effective mechanism to assist the animal in adapting to changes in its environment. The physiological outcomes include adjustments in metabolic rate, cardiac function, blood pressure, peripheral circulation, respiration, visual acuity and energy availability and use that allow the animal to meet physical and/or emotional challenges. Corticosteroids in the short-term also reduce some of the damaging effects of the immune response, such as repressing the inflammatory response. There are also some behavioural adaptations as a consequence of the short-term activation of the SAM and HPA axes, such as increased arousal and alertness, and increased cognition, vigilance and focused attention (Mendl, 1999; Kaltas and Chrousos, 2007), that should assist the animal to search, scrutinize and remember threatening or rewarding situations.

If the stressor continues, the response proceeds to what is termed a chronic stress response, and it is this series of events that can have serious consequences for the animal. The chronic stress response is also a corticosteroid-dependent mechanism, but while in the acute phase the effects are potentially beneficial, this chronic activation of the HPA axis comes at a physiological cost to the animal, such as a decreased metabolic efficiency, impaired immunity and reduced reproductive performance. Therefore, the long-term activation of the HPA axis can have marked effects on efficiency of growth with for example the breakdown of muscle protein under the catabolic effects of ACTH and corticosteroids (Elsasser *et al.*, 2000). Corticosteroids also support the synthesis and action of adrenalin in stimulating glycogenolysis (i.e. provision of glucose from liver and muscle glycogen for the required increased metabolic performance) and lipolysis (provision of energy in the form of free fatty acids from the breakdown of adipose tissue) (Matteri *et al.*, 2000). Stress-induced changes in the secretion of pituitary hormones have also been implicated in failed reproduction (Breen and Karsch, 2006) and immune competency (Blecha, 2000). In sows, stress as well as reduced feed intake and increased injuries have been implicated in reduced reproductive performance and increased culling caused by reduced floor space allowance (Barnett et al., 2001; Spoolder et al., 2009). The seriousness of these costs depends on how long the animal is required to divert physiological resources to maintain homeostasis.

The concept of biologically active cortisol is important because of its implications for determining the magnitude of a stress response and its consequences. A predominant feature of a chronic activation of the HPA axis is increased basal secretion of corticosteroids with a loss in diurnal regulation of the axis (Harbuz and Lightman, 1992). It is this sustained elevation in free corticosteroids, together with changes in other hormones, cardiovascular function, metabolism and the immune system, that has broad, long-lasting effects on the body such as decreased metabolic efficiency, impaired immunity and reduced reproductive performance. In other words, increased basal secretion of corticosteroids have significant fitness consequences for the animal, and it is these biological and fitness effects that reflect both the magnitude of the stress response and the welfare implications.

While the role and actions of corticosteroids in acute and chronic stress responses are well known, this is not to imply that the HPA axis is the only neuroendocrine axis affected by stressors. There is also involvement of the somatotrophic and thyroid axes and other hypothalamic and pituitary hormones such as arginine vasopressin and prolactin, respectively. Furthermore there is also a direct involvement of the immune system. While corticosteroids can suppress the immune system (Blecha, 2000; Kaltas and Chrousos, 2007), studies using various stress models show that factors other than corticosteroids may also be involved in the stress-induced immunosuppression observed in animals transported, restrained or isolated (Blecha, 2000).

It is clear that the hormones secreted from the HPA axis have broad, long-lasting effects on the body and thus challenges to homeostasis that result in such neuroendocrine responses clearly have implication for animal welfare. This is not surprising when one considers the actions of catecholamines and corticosteroids. While their actions generally have clear benefits in the short term in dealing with stress, the longer-term effects can have harmful physiological outcomes that negatively impact welfare. Furthermore, while some component of behaviour is likely to be involved in every stress response, behavioural responses may not be appropriate or effective for all situations. Indeed, redirected behaviours and stereotypies, as with long-term neuroendocrine responses, may indicate difficult or inadequate adaptation. Therefore, measuring both these behavioural and physiological responses to a stressor, which reflect the challenge confronting the animal, as well as the fitness consequences of these responses for the animal, clearly affords an insight into the risks to the animal's welfare.

Cortisol is the principal corticosteroid in pigs and the HPA axis can be activated by physiological insults such as infection, pain, injury and malnutrition and by psychological challenges such as fear, social isolation and transport stressors (Barnett et al., 2001; Hemsworth and Coleman, 2011). Changes to the plasma concentration of corticosteroids can be easily measured and an increase in plasma corticosteroid concentration has become a commonly accepted indicator that an animal is experiencing stress. Plasma corticosteroids concentrations have been measured to evaluate mulesing, sow housing, transport stress, hen cage design and dairy systems, and are a good indicator of HPA axis activity.

However, there are several criticisms that are often raised in regard to the measurement of physiological criteria when assessing animal welfare and Barnett (2003) discussed these as follows. The first criticism is in deciding the concentration of corticosteroids that is symptomatic of reduced welfare. In a review of experiments conducted on the effects of handling and housing of pigs, Barnett and Hemsworth (1990) concluded that subsequent or concurrent detrimental consequences, such as (1) changes in plasma concentrations of glucose, urea or protein indicative of a significant metabolic cost to the animal, (2) immunosuppression indicative of a potential health risk and depressions in growth rate, pregnancy rate or (3) sexual behaviour indicative of a production efficiency loss, generally occur when increases in free corticosteroids of greater than 40% occur. Since nutritional state, immune status, reproductive status, and seasonal and circadian rhythms affect concentration of corticosteroids, it is necessary to have an appropriate cohort of animals as controls when studying the animal welfare implications of a particular practice. A similar problem occurs when we ask a question about what is a high level of an abnormal behaviour? At what point should we be concerned about the animal's welfare? Again it is necessary to have an appropriate cohort of animals as controls to understand if a particular practice increases the level of abnormal behaviour.

Another criticism relates to measurement because of the potential difficulty of sampling without disturbing the animal and sampling problems associated with diurnal rhythms of physiological variables. However, these are just technical problems and providing there is a good understanding of the diurnal patterns of hormone release in the species, good experimental technique can account for these variables; for example blood can be sampled using indwelling catheters and remotely if necessary from behind blinds or alternatively there are remote back-pack samplers available. In pigs it has been shown that taking samples hourly during daylight is highly correlated with samples taken every 20 min over 24 h and thus these problems just represent a challenge to the scientist and are not really a valid criticism (Barnett *et al.*, 1981). Indeed, non-invasive procedures are currently in favour, such as analysis for corticosteroids or their metabolites in saliva (Kobelt *et al.*, 2003), faeces (Palme *et al.*, 2000), urine (Carlstead *et al.*, 1992) and eggs (Downing and Bryden, 2008). Other measurement issues relate to what is being measured and an understanding of the stress response. Thus, it is important to distinguish between total and free cortisol concentrations as the former is not related to biological activity (Barnett, 2003).

A third criticism is the interpretation of acute stress responses as these can occur in response to pleasant as well as unpleasant stimuli. For example, mating in rats (Szechtman et al., 1974) and perhaps voluntary exercise in man (Sutton and Casey, 1975), could be described as not being unpleasant and both result in increased corticosteroid concentrations and thus care must be taken not to interpret all acute stress responses as signifying reduced welfare. Notwithstanding this limitation, it is possible to use the duration and intensity of the acute stress response to address specific management procedures that minimize acute stress responses. Nevertheless, it must be remembered that acute stress responses are by definition, short-term, do not generally have long term detrimental consequences and thus are often difficult to interpret in terms of welfare. It is also currently difficult to distinguish between acute and chronic stressors. Indeed, chronic stressors have been viewed as a series of intermittent acute stressors (Ladewig, 2000). In chronic stress there is some evidence that the sensitivity of the pituitary gland to CRH is reduced, although the release of ACTH is maintained by arginine vasopressin (Dallman, 2000). Nevertheless, the distinction between acute and chronic stress is moot if the focus is on the consequences of the stress response rather than the mechanisms involved.

Another criticism concerns the relative importance of physical and psychological factors on physiological variables. There is no doubt that emotions are potent stimulators of the HPA axis (Mason, 1968). However, while it may be difficult to be certain of the precise nature of the stressor if emotions are involved, emotional factors can easily be incorporated into the stress concept and as emphasized, it is the consequences of the stress response that are important to welfare and not the cause(s) of the response.

3.4. Immunology

It is becoming increasingly well-understood that the immune system in its own right is one of the major defence systems responding to a stressor. The increased incidence of disease in animals suffering from stress has long been recognized as a consequence of modulation of the immune system principally by the HPA axis. However, the central nervous system has a direct role on regulation of the immune system (Moberg, 2000). Furthermore, while the adrenal, somatotrophic and thyroid axes have a critical role in shaping metabolism under the influence of stress, it is also clear that endocrine-immune interactions are also important (Elsasser *et al.*, 2000). Animals under stress have increased risk of infection because they may be immuno-suppressed (Moberg, 2000). Stress can have direct effect on the health status of pig herds, resulting in widespread clinical and subclinical disorders that compromise the welfare of the animals (Hughes and Curtis, 1997). There is a close relationship between stress and illness. Herbert and Cohen (1994) suggested that the arousal of the sympathetic nervous system might lead to illness and the authors argued that the release of adrenalin and noradrenalin has direct effects on the immune system because some of the sympathetic nerves end on organs of the immune system, thereby altering their functioning.

Immune parameters associated with a chronic activation of the HPA axis affect the reactive capabilities of cell mediated immunology (Herbert and Cohen, 1994). These include an overall reduction of white blood cell numbers, antibody production, neutrophil function, lymphocyte proliferation, and natural killer cell activity and an increase in acute phase protein response and levels of pro-inflammatory cytokines (Black *et al.*, 2001). White blood cells have receptors for adrenalin, noradrenalin and cortisol and increased cortisol concentrations have been associated with reduction in lymphocyte populations, lymphocyte proliferative response and natural killer cell cytotoxic activity (Elsasser et al., 2000; Herbert and Cohen, 1994). Variations in white blood cell populations and reduced lymphocyte activity may lead to a diminished immunological reaction against disease outbreaks and increase the risk of infection from injuries. Stress does not simply suppress the immune system, but induces a shift in the cytokine balance resulting in immune dysfunction. Such changes increase susceptibility to infection, fever, and hypersomnia and depress social behaviour (Gregory, 1998). While there is a general thinking that corticosteroids are immuno-suppressive, there is some evidence that they can be immune-enhancing and the nature of the effects depends on the timing of corticosteroid responses; an acute stress response 2 h prior to a skin test resulted in immune-enhancement in rodents (see Dhabhar, 2002). A recent experiment in poultry showed that corticosterone given for 5 or 2 days prior to an immune challenge resulted in immune-enhancing and an immunosuppressive effects, respectively (Lopez et al., 2007). These data suggest that an acute stress response may be immune-enhancing, while a chronic response (a more sustained elevation of corticosteroid concentrations) is immunosuppressive.

3.5. Abnormal behaviour

In this review, we use the term 'abnormal behaviour' as shorthand to include behaviours such as displacement, redirected and stereotypic behaviours. The use of the term abnormal behaviour in domestic animals invariably raises questions about what is normal (Price, 2010), particularly when most behavioural differences between wild and domestic animals appear to be quantitative rather than qualitative in character, and best explained in differences in response thresholds (Price, 2003). Considered as an aspect of the behaviour of an animal, abnormal behaviour is frequently defined as behaviour that is either atypical for the species, outside the normal behaviour pattern that has evolved in the natural habitats of the species or outside the range usually observed in the species in non-captive situations (Keeling and Jensen, 2009). It has been proposed that the welfare of the animal is at risk if stereotypies occur for 10% of the animal's waking life (Broom, 1983) and if they occur in more than 5% of all animals (Wiepkema, 1983). Suffering and maladaptiveness are criteria often used when referring to abnormality of behaviour (Seligman and Walker, 2000; Price, 2003).

While research has led to a better understanding of the causation of some abnormal behaviours in animals in captivity, the function and, thus, adaptive significance of abnormal behaviours are often poorly understood. For example, the stereotypies of bar-biting and vacuum chewing (champing) of stalled- or tethered-housed sows may be redirected foraging behaviours and/or conditioned responses arising from restricted feed intake (Lawrence and Terlouw, 1993), while wool-biting in confined sheep may be a redirected foraging behaviour arising from reduced foraging opportunities (Vasseur et al., 2006).

Therefore, in this review the range of behaviours labelled as 'abnormal' are behaviours that are commonly seen in pigs, but are regarded as abnormal behaviours when their prevalence and incidence exceed what is seen in an extensive setting.

Survival of even the simplest animal depends on the ability of the animal to locate food, water, shelter and other requirements, and to avoid injury, illness, predators and parasites. Behaviour is a key response in achieving these outcomes. From evolutionary biology, we learn that behaviour evolves for the good of the individual. Such benefits ultimately have to be measured in reproduction and indeed evolutionary biologists refer to reproductive success of an individual as its fitness. Thus animals behave in ways to maximize their individual fitness, which will ultimately enable their genes to spread. However we need to recognize that a behaviour not only has potential fitness benefits arising from its performance but also costs. It may consume valuable energy, which otherwise could be used for reproduction, or it may damage (injury) or threaten (exposure to predator or competitor) the animals. Evolution will select the behaviour that maximizes fitness (Maynard Smith, 1978).

As discussed earlier, stressors will elicit behavioural responses often in combination with responses of the autonomic nervous system, the neuroendocrine system and the immune system (Moberg, 2000). Furthermore, for many stressors the first and, at times, the most biologically economical and effective response is a behavioural one. While some component of behaviour is likely to be involved in every physiological stress response to an external stimulus, behavioural responses are often specific to the type of stressor. Short-term behavioural responses may include an orientation, startle and defensive or flight reactions, but long-term behavioural responses may include stereotypies (Broom, 1983; Broom and Johnson, 1993), apathetic behaviour (Broom, 1986; 1987), rebound behaviour, displacement and redirected behaviours (Borell *et al.*, 1997; Cronin *et al.*, 2003).

Stereotypies may be a strategy that the animal uses to modify its motivational state in response to unpleasant stimuli or the lack of motivation (Broom, 1983). Examples of stereotypies include pacing, weaving and wind-sucking in stabled horses (Mills *et al.*, 2002), tongue rolling and bar biting in tethered dairy cows (Redbo, 1993) while bar biting, licking and vacuum chewing (champing) are amongst the most common in pigs (Vieuille-Thomas *et al.*, 1995). Rebound behaviours are behaviours that a confined or restrained animal performs in an excessive way when the opportunity arises and include galloping and bucking in calves (Jensen et al., 1998), wheel-running in rats (Mueller, 1999), social grooming and play behaviour (and increased aggression) in stallions (Christensen *et al.*, 2002), wing-flapping and pacing in hens (Nicol, 1987; Fraser 1975) and barking in dogs (Cronin *et al.*, 2003). Animals may redirect some behaviours when faced with stressful situations. Examples include laying hens redirecting their behaviour from ground pecking to feather pecking following a change from a pen with a floor that was half litter and half slatted to a fully slatted pen (Blokhuis, 1989) and pigs affected by unpredictable cold air currents performing redirected exploratory behaviour and ear biting that increased aggression amongst pen mates (Scheepens *et al.*, 1991).

Abnormal behaviours, such as stereotypies, are generally agreed to be indicative of poor welfare because they are the animal's behavioural and often first level of response to challenge. For example, stereotypies are considered evidence of a poor physical and social environment and/or inadequate nutrition (Barnett et al., 2001). However, there is still on-going discussion and research on the welfare significance of these abnormal behaviours, particularly stereotypies (Mason and Rushen, 2006).

While redirected and displacement behaviours may lead to stereotypies if the problems persists, there is evidence that in some situations stereotypies may be adaptive. For example, based on early evidence of associations between stereotypies and physiological signs of coping such as reduced corticosteroid concentrations, reduced adrenal gland weights, and reduced ulceration, there is a view that stereotypies may be a coping response (Barnett et al., 2001). However, more recent studies and re-interpretation of some of the early evidence question this general coping hypothesis for at least some forms of stereotypic behaviours (Mason 1991; Rushen 1993). As concluded by Mason and Latham (2004) "Beneficial consequences from performing the specific source-behaviour of the stereotypy (‘do-it-yourself enrichment’) or arising from the repetition per se (‘mantra effects’) may ameliorate welfare in poor environments.....In addition, stereotypies that have centrally controlled (habit-like) or that arise from autistic-like changes in the control of all behaviour (perseveration), are likely to be unreliable indicators of current state because they can be elicited by, or persist in, circumstances that improve animal welfare.” Irrespective of the function of stereotypies, the existence of a stereotypy is indicative at the least of a past problem for the animal in coping with its conditions (Barnett et al., 2001). Stereotypies that result in physical damage to, or illness in, the animal (e.g. the development of lesions in stall-housed sows that persistently rub their tail roots from side to side against stall fittings or wind-sucking in horses where persistent wind-sucking can lead to gastrointestinal catarrh and colic) have obvious and immediate implications for the welfare of farm animals. Thus, although stereotypies (and other abnormal behaviours) should not be used alone, they can be used together with other biological responses and their consequent effects on biological fitness, to assess risks to animal welfare.

3.6. Animal preferences

Tests of preference and motivation have been used to determine what resources or behaviours are important to an animal. Initial use of preference methodologies appeared in the literature in the 1970s (e.g., Hughes and Black, 1973; Dawkins, 1976). Preference testing using a Y maze apparatus that allows a choice between access to two different resources has been used to provide information about specific features in an animal’s environment, such as flooring on raceways (Hutson, 1981), restraint methods (e.g., Pollard *et al.,* 1994), handling treatments (Rushen, 1986) and ramp design (Phillips *et al.*, 1988), with the overriding objective of optimizing captive environments for animal inhabitants.

While the consistent choice or preference of one resource over another or others indicates the animal’s relative preference not absolute preference, some have argued that in addition to establishing what an animal prefers, it is important to understand the strength of the preference (Dawkins, 1983; Matthews and Ladewig, 1994). To address the question of the strength of an animal’s preference, experiments have incorporated varying levels of cost (e.g., work effort, time and relinquishing a desirable resource) associated with gaining access to a resource or avoiding aversive stimulation. For example, Dawkins (1983) varied the price paid for access to litter by increasing the duration of feed withdrawal before the test. She found that although hens preferred litter to wire floors, their preference was not strong enough to outweigh the attraction of food and concluded that in both experiments there was no evidence that hens regarded litter as a necessity.

Furthermore, Dawkins (1983) suggested that quantitative measures of the importance of resources for animals can be derived from measures of demand elasticity. Consequently, ‘behavioural demand’ studies, using operant conditioning techniques in which the animal must learn to perform a response, such as pecking at a key or pushing through a weighted door, to gain access to a resource, have been used to study the animal’s level of motivation to access or avoid the situation being tested. For example, Matthews and Ladewig (1994) studied the behavioural demand functions of pigs for the resources of food, social contact and a stimulus change (door opening). The amount of work, in the form of pushing a plate, required for access to each reinforcer (resource) was systematically varied. It was found that while the demand for opening the pen door was highly elastic (i.e. the willingness of the pigs to access the resource declined as the effort increased), the demand for food was inelastic and the demand for social contact was intermediate.

Preference and motivation testing have generated considerable debate relating to conceptual and methodological difficulties (see Fraser and Nicol, 2011). For example, familiarity with a resource may affect choice, a choice at a point in time may not reflect interactions of different motivational states over time, a positive resource may remind the animal of a resource that it may not otherwise miss, the choices may not be within the animal's cognitive capacity and vigilance behaviour may be misinterpreted as a choice. Furthermore, as with biological functioning, clarifying the conceptual link between animal preferences and animal welfare is difficult. Nevertheless, as argued by a number of authors (e.g. Fraser and Matthews, 1997; Widowski and Hemsworth, 2008), while studies of motivation can provide evidence that the performance of some behaviour (or preference) may be important to the animal, additional evidence, particularly on the occurrence of abnormal behaviour, stress physiology and health, are necessary to provide a more comprehensive assessment of the impact of restriction on animal welfare.

3.7. Hunger

Hunger *per se* is a welfare concern and the restricted diet commonly fed to pregnant sows results in constant hunger (Barnett et al., 2001). Furthermore, the conventional restricted feeding in group housed sows increases hunger and, in turn, competition and aggression for feed or access to feeding areas (Barnett et al., 2001). Feed restriction and the inability to express the resulting foraging behaviour are considered a major cause of the development of stereotypies in sows (Lawrence and Terlouw, 1993). However, such 'foraging' stereotypies can be influenced by feeding method and housing system (Barnett et al., 2001).

In addition to hunger, feeding patters may be affected by diurnal patterns, that in turn are determined by management practices. However when feed is freely available, pigs in groups will consistently occupy feeders throughout the day (Morrison et al., 2003). Feeding patterns are also affected by social facilitation (Ligout, 2010).

Behavioural demand (motivation) tests have generally used to assess sow hunger and are considered an effective way of measuring feeding motivation (Robert et al., 2002; Kirkden and Pajor, 2006; D'Earth et al., 2009). Subjects are required to perform a response for access, such as pressing a lever and if the response is acquired, this demonstrates motivation. In addition, the number of responses is equated to the level of motivation Kirkden and Pajor, 2006). Stereotypies in pregnant sows relate to feeding motivation (Terlouw et al., 1991; Spoodler et al., 1995) and researchers have used the frequency of stereotypies associated with dietary fibre and energy to assess hunger (e.g. Robert et al., 1997).

Both feeding physiology (e.g. measures of energy substrates such as glucose and NEFA, and the hormones that regulate them, such as insulin and glucagon) and stress physiology (e.g. glucocorticoids or corticosteroids such as cortisol and corticosterone) have been underused to study hunger, but the physiological indicators of hunger are often poorly correlated with the behavioural indicators and the difficulties associated with such measures are discussed by D'Earth et al. (2009).

3.8. Sexual behaviour and reproductive performance

The concept of biological fitness generally applies to natural populations and refers to 'fitter' animals having a greater genetic contribution to subsequent generations because of their increased ability to successfully survive, grow, and reproduce (Barnett et al., 2001). Although the last attribute may not always apply to individual farm animals since reproduction is either controlled or absent for many farm animals, the ability to grow, survive, and reproduce can be considered measurements of 'fitness' within the limits of the management system. Most production systems in agriculture have breeding and growing components and these can generate considerable data on reproductive success of individuals. For example, conception rates and mortality, morbidity, and growth of offspring can be used as a measure of 'fitness'. Similarly, Beilharz and Zeeb (1981) and Beilharz (1982) have linked reproductive performance of domestic species with welfare.

Turner et al. (2005) in a review of the literature concluded that prolonged stress and sustained elevation of cortisol can disrupt reproductive processes in female pigs, although a proportion of female pigs appear to be resistant to the effects of prolonged stress or sustained elevation of cortisol. Spoolder et al. (2009) recommended that stress should be avoided to minimize reproductive failure, especially in weeks 2–4 of pregnancy in which the two sensitive reproductive events occur, the period of attachment of embryos to the uterine wall (days 11–16) and the period shortly thereafter, because in this period, the so-called 'maternal recognition of pregnancy' takes place with many associated hormonal changes.

The lifespan of commercial sows is often reduced to approximately 2 years (Marchant-Forde, 2009) in comparison to 15 years in the wild (Pond and Mersmann, 2001). This is in part attributed to the culling of sows due to injury, disease, or reduced reproductive performance. Thus culling due to such fitness costs can be considered a useful welfare measure.

While relative changes in biological (behavioural and physiological) responses can lead to corresponding decreases in fitness variables such as reproductive performance and injury and health, such biological changes can lead to decreases in efficiency of growth, which thus can be considered fitness variables.

3.9. Conclusions on welfare assessment

Sow welfare in this review will be assessed using measures of biological functioning. The main measures used will include behavioural variables, such as aggression, and displacement, redirected and stereotypic behaviours, physiological variables, such as cortisol and neutrophil-lymphocyte ratio, and fitness variables, such as lameness, skin lesions, live weight change and reproductive performance. Few studies have used tests of preference and motivation to study what resources or behaviours are important to sows in groups. Behavioural demand tests have been used to assess sow hunger and, apart from one study by Kirkden and Pajor (2006) to assess the preferences of sows for group housing rather than stall housing, there has been no research on sows' preferences for features of group housing.

4. Factors affecting the welfare of sows in groups

In the establishment of a group of sows, aggression is a basic feature of the formation of a dominance hierarchy. The term 'dominance' refers to the predictable relationships between a pair of conspecifics, where one has learnt to dominant the other animal (subordinate), which in turn tends to avoid the confrontations between the two (Lindberg, 2001). Once established, the dominance hierarchy functions to reduce the need for aggression and consequently injury.

A major challenge when housing pigs of any age in groups is aggression. Pigs will fight especially when mixed and competing for access to limited resources and it is the occurrence of persistent aggression that reduces pig welfare, predominantly through increased stress and injury and restricted access to feed and preferred lying areas. Furthermore as a consequence of stress and reduced feed intake, pig productivity in terms of efficiency of growth and reproduction is also at risk. Thus this review of factors affecting the welfare of group-housed sows will focus on those factors affecting aggression, injuries and stress.

In addition to research on sows in groups, considerable research has been directed towards understanding the effects of grouping on the behaviour and growth performance of younger pigs. Some of this research on young pig is applicable to understanding group effects on sows, however caution is required because of obvious differences for sows such as effects of experience, restricted feeding, feeding systems such as floor feeding and feeding stalls and stage of the reproductive cycle.

4.1. Floor space allowance

Floor space, both quantity (amount) and quality (configuration, including physical and visual barriers) affects aggression by allowing sows to avoid and escape others. It is important to provide sufficient space, both quantity and quality to allow sows to establish a dominance hierarchy (Lindberg, 2001) and failure to do so may prolong aggression. Research has shown that reducing floor space within the range of 1.4 to 3.0 m^2/sow increases aggression and stress in gestating gilts and sows.

Aggressive behaviours, such as bites and butts, and basal concentrations of plasma cortisol were generally higher and immunological responsiveness, assessed on the basis of a cell-mediated response to a mitogen injection, was lower in pregnant gilts at a space allowance of 1.0 than 1.4 or 2.0 m^2/gilt at 2 to 54 days of treatment (Barnett et al., 1992; Barnett, 1997). Similarly in pregnant gilts, basal cortisol concentrations were higher at 1.0 than 2.0 or 3.0 m^2/gilt at 9 to 11 and 67-76 days of treatment (Hemsworth et al., 1986). A lower percentage of gilts were detected in oestrus at 1.0 than 2.0 or 3.0 m^2/gilt (Hemsworth et al., 1986).

For sows mixed soon after insemination, Hemsworth et al. (2013) found that increasing floor space from 1.4 to 3.0 m^2/sow reduced both aggression at feeding and plasma cortisol concentrations at day 2 of treatment, and increased farrowing rate. The authors concluded that although the results are in accord with a linear decline from 1.4 to 3 m^2/sow, the results are also in accord with a decline in these measurements from 1.4 to 1.8 m^2/sow and no further decline greater than 1.8 m^2/sow. While several thousand sows were involved in this experiment, the size of the experiment turned out to be insufficient to determine which of these scenarios was more biologically correct. The authors also concluded that in terms of animal welfare at mixing, it is impossible to provide guidance on an adequate space allowance, other than a space allowance of 1.4 m^2/sow is too small.

It is of interest that although space affected sow aggression and cortisol at day 2 in the experiment by Hemsworth et al. (2013), there was no evidence that space affected aggression at day 8 or basal cortisol concentrations at days 9 and 51 of the experiment. One interpretation of this pronounced effect of space early after grouping is that static groups may adapt, either behaviourally or physiologically, over time to reduced space. Clearly, there is a need to examine the effects of reducing space during gestation because this effect may offer the opportunity for ‘staged-gestation penning’ in order to provide increased space immediately after insemination.

The numbers of head interactions, including bites, and nose interactions with other sows, threats and withdrawals at days 6 and 7 of treatment were generally higher in established groups of pregnant sows at 2.0 than at 2.4, 3.6 and 4.8 m^2/sow (Weng et al., 1998). While reciprocal aggressive behaviour (bites or knocks) did not differ, Remience et al. (2008) found that non-reciprocal aggression at days 3 and 8 after mixing was higher in pregnant sows at 2.25 than at 3.0 m^2/sow.

In the studies by Barnett et al. (1992), Barnett (1997) and Hemsworth et al. (2013), although space affected aggression and stress, there were no effects of space on skin injuries. In contrast, Weng et al. (1998) found that fresh skin injuries (cuts and scratches) in sows in groups of 6 at day 7 were greater at 2.0 than 2.4 m^2/sow, which in turn were greater than in 3.6 and 4.8 m^2/sow. Salak-Johnson et al. (2007), in which sows were mixed in groups of 5 once confirmed pregnant, found that skin scores were consistently higher at a space allowance of 1.4 m^2/sow than at 2.3 or 3.3 m^2/sow. Similarly, Remience et al. (2008) found that fresh superficial and deep skin injuries were higher at weeks 1 and 2 and week 1 after grouping, respectively, in dynamic groups of sows provided with 2.25 than 3.0 m^2/sow. These experiments differ in terms of the effect of space on injuries, however the consequences of fighting on skin injuries may be reduced in very confined conditions.

There are several differences between these experiments. Some studied gilts while others studied sows. Furthermore, some studied gilts and sows once confirmed pregnant (Hemsworth et al., 1986; Barnett et al., 1992; Barnett, 1997; Weng et al., 1998; Salak-Johnson et al., 2007; Remience et al., 2008), while Hemsworth et al. (2013) studied sows soon after insemination. Both floor and ESF and static and dynamic groups were also utilized in these experiments. Nevertheless, these results indicate that space can affect aggression, injuries and stress physiology. However, the space allowance at which sow welfare, based on aggressive behaviour, injuries, cortisol concentrations, immunological responsiveness and farrowing rate, is compromised is difficult to assess from these results, except that 1.0 m^2/gilt and 1.4 m^2/sow is insufficient. Clearly, further research is required to examine in more detail the effects of space allowance in the range of 1.8 to 2.4 m^2/sow, with particular attention given to the effects of space in the first week after mixing recently-inseminated sows because this is the period when effects on aggression and stress are likely to be most pronounced. Furthermore, the results of Hemsworth et al. (2013) indicate that the sow's requirement for space, based on aggression and stress, is less once the group is established, for example by day 8 or 9 after mixing. Thus, further research is also required to examine the effects of reducing space during gestation because this effect may offer the opportunity for 'staged-gestation penning' in order to provide increased space immediately after mixing.

4.2. Group size

In the establishment of a group of sows, aggression is a basic feature of the formation of a dominance hierarchy. The natural grouping of sows in the wild is relatively small and thus dominance hierarchies are easily formed. The expectation is that aggression will increase as a function of group size (Arey and Edwards, 1998). In large groups where individual recognition becomes less likely, animals may use different strategies to create social hierarchies (Lindberg, 2001). Laying hens in large groups use methods other than aggression to establish social dominance, such as body weight (D'Eath and Keeling, 2003), a tactic that sows in large groups may also employ. Subordinate hens show preference for larger groups (Lindberg, 2001), perhaps because they can blend in easier and avoid the attention of aggressive hens. It is also possible that larger number of animals provide more shelter for targeted sows, allowing them to hide behind others or escape into the group. In addition to this non-interventionist strategy, they may also form sub-groups in which social hierarchies may develop, although there is little or no evidence of this in domestic fowl (Lindberg, 2001). Domestic sows may form sub-groups (Anil et al., 2006), such as those that occur in the wild, that avoid mixing. Sub-groups have been observed in groups of 40 sows at least in terms of lying behaviour (Taylor et al., 1997). However as Gonyou (2001) notes, it is not clear if these sub-groups remain distinct during periods of activity or only exist during lying. If sub-groups remain distinct during activity, it suggests territorial or at least well-defined home ranges within pens with large groups.

Although aggression measured on the first and second day of grouping increased as group size increased, Taylor et al. (1997) found that varying group sizes, of 5, 10, 20, and 40 sows with a space allowance of 2.0 m^2/sow, had no effects on the number of lesions measured on days 5 and 53 or reproductive performance (proportion of sows that farrowed, piglets born per sow, and piglets born per sow alive, stillborn, or mummified). While there was no effect of group size on frequency of fighting in the first and third hour after mixing or on the second day, duration of fighting increased as group size increased but only in the first hour after mixing. In contrast, while aggression at days 2 and 8, cortisol concentrations at days 2, 9 and 51 after mixing and reproductive performance were not affected by group size, Hemsworth et al. (2013) found that the incidence of skin injuries throughout gestation was affected by group size in gestating sows, with groups of 10 generally having consistently lower injuries than groups of 30 and 80. In an experiment examining small group sizes, Barnett et al. (1984, 1986) found that housing sexually mature gilts in pairs had increased cortisol concentrations compared to housing in groups of 4 to 8 with a similar space allowance. In an unpublished study, Hansen (2002a) reported that in one of two commercial herds in which group-housed sows mixed early after insemination were studied, the proportion of sows culled for non-reproductive reasons such as injuries and leg and hoof condition, was lower in those sows in groups of 6-7 sorted on the basis of size than sows randomly allocated to large groups of 20. Olsson et al. (1994) reported group size effects on skin injuries, but group size was confounded by space, feeding system and presence of bedding.

While the literature on effects of group size on aggression and injuries are contradictory, there is no evidence that large group sizes of 20 to 80 affect stress or reproductive performance. However there is evidence in one experiment that duration of aggression but not injuries increases in larger groups, while another indicates that injuries but not frequency of aggressive interactions increases in larger groups. Other factors such as flooring and competition for feed or access to feeding areas may have a greater impact on aggression, injuries, stress and reproduction than group size.

4.3. Nutrition and hunger

4.3.1. Feeding level

Restricted feeding of sows during gestation assists in maximizing economic performance (Meunier-Salaun et al., 2001) however under feeding may adversely affect reproductive performance (Virolainen et al., 2004, 2005; Langendijk and Peltoniemi, 2013). Indeed to minimize pregnancy losses of group-housed sows during early gestation, it is recommended that individual feed intakes should not be less than 2.0 kg/day for gilts and 2.5 kg/day for sows (Pork CRC, 2013). Nevertheless, these recommended minimum intakes increase hunger and, in turn, increase competition in group-housed sows for feed or access to feeding areas (Barnett et al., 2001).

The restricted-diet commonly fed to pregnant pigs results in hunger (Barnett et al., 2001). Although the restricted level of feeding during gestation is generally sufficient for maintenance, some growth, and fetal development, it also results in pigs being highly motivated to feed. Operant conditioning studies have shown that boars and sows are prepared to work for a feed reward to a degree that suggests that they are hungry for a considerable period of the day (Hutson, 1991; Lawrence and Terlouw, 1993). In operant conditioning tests, Bergeron et al. (2000) found that sows fed a control diet (5% crude fibre) *ad libitum* obtained less feed rewards than restrictively-fed sows on either high levels of high fibre diets (3.5 (18% crude fibre) and 4.5 kg/day (23% crude fibre)) or the control diet (2.5 kg/day).

Chain and bar manipulation in pregnant sows are often regarded as stereotypic behaviours. Lawrence and Terlouw (1993) proposed that feed restriction and the inability to express the resulting foraging behaviour are a major cause of the development of stereotypies in sows. They argued that the positive feedback effects of feeding in the early stages of a meal in food-restricted sows overrides the negative feedback from ingestion of nutrients, resulting in higher levels of feeding motivation after the meal than before it. In an environment where appetitive behaviour cannot be performed in a satisfactory way, where the animal's movements are restricted or where there is simply no available foraging substrate, Lawrence and Terlouw (1993) suggested that appetitive behaviour may be performed repetitively with a less appropriate substrate, leading to the 'channelling' of complex behaviour into a few repeated sequences. Stereotypies have been shown to develop in feed-restricted sows (Terlouw et al., 1991), but there is no consistent evidence of increased stress based on plasma and urinary cortisol concentrations in feed-restricted sows (see review by Meunier-Salaun et al., 2001).

Sows fed 1.8 kg (23 MJ DE/day) spent more time after feeding standing and manipulating bars and chains than sows fed 3.2 kg (40 MJ DE/day) (Spoolder et al., 1995). There were also no effects of feeding level on aggression or skin injuries in these group-housed sows, but the sows in this experiment were locked in individual feeding stalls for 1 h daily after feeding which would limit aggression between sows. In a study of sows in dynamic groups with ESF and deep-litter straw, Spoolder et al. (1997) found no effects of feeding level (3.0 kg and 38 MJ DE/day or 1.6 kg and 20 MJ DE/day) on aggression or skin lesion scores. Bergeron et al. (2000) found that stall-housed sows fed a control diet *ad libitum* spent less time displaying stereotypies than those restrictively-fed the same diet (2.5 kg and 40 MJ DE/day).

It is also of interest that Bergeron and Gonyou (1997) found that sows fed either a high energy diet (23.7 MJ/kg) or a 'high-foraging' diet (a standard diet (14.0 MJ/kg) but a device in the feeder increased the feeding time) spent less time activity and less time displaying stereotypies than sows fed a standard diet (14.0 MJ/kg). This study suggests that lack of energy in the diet as well as time spent feeding contribute to the development of stereotypies. However, while increased feeding times have been shown to reduce sow hunger, the practice can also crowd sequential feeding systems, such as protected ESF, thereby reducing overall feeder capacity within a sow group (Bench et al., 2013a).

Stereotypies have been shown to develop in feed-restricted sows, but while few studies have been specifically conducted, there is no consistent evidence of increased aggression, stress or injuries in feed-restricted sows. There is limited evidence that a lack of energy in the diet may contribute to the development of stereotypies.

4.3.2. Fibre including foraging substrates

Increasing fibre content in a sow diet prolongs feeding time and gastro-intestinal distension, hence lengthening the metabolic state (Robert et al., 1997; Vestergaard et al., 1997), which in turn may increase satiety and consequently reduce feeding motivation. Furthermore, increased fibre content may also reduce the development of stereotypies arising in feed-restricted sows because of effects on satiety. However, the literature on the impact of a high fibre diet on feeding motivation at first glance appears contradictory.

The effects of fibrous diets (e.g. inclusion of high fibre ingredients such as oat hulls, straw, sugar beet pulp and wheat bran) on feed motivation of sows has been studied by using operant conditioning procedures where for example sows have to perform a task such as paddle pressing and the level of feeding motivation is evaluated according to the number of presses or food rewards obtained. Lawrence et al. (1989), Bergeron et al. (2000) and Ramonet et al. (1998, 2000) have shown that feeding restrictively-fed pigs high fibre diets (e.g., 3.5 (18% crude fibre) and 4.5 kg/day (23% crude fibre) of a sugar beet diet, Bergeron et al., 2000; and 2.7 (93 g CF) of a sugar beet diet and 2.9 kg/day (213 g CF) of a wheat bran, Ramonet et al., 2000) does not affect their operant responses to a feed reward, suggesting that they are still hungry. In contrast, other studies have shown that fibre can reduce feeding motivation (e.g., 2.9 (10% CF) of a wheat bran and corn cobs diet and 3.6 kg/day (20% CF) of an oats hull and oat diet, Robert et al., 1997; 3.1 kg/day (18% CF) of an oat hulls and alfalfa diet, Robert et al., 2002). Differences in methodology, such as the schedule, duration and time of day of the tests, food reward, fibre content and quality, and feeding levels, may account for these contrary findings. For example, Robert et al. (1997) used their experimental high-fibre diet as food reward, whereas other investigations used a standard diet (Lawrence et al., 1988; Hutson, 1991; Ramonet et al., 1998).

Furthermore, De Leeuw et al. (2004, 2005) found that sows fed a high level of fermentable dietary fibre (900 g sugarbeet pulp twice daily) had stabilized blood glucose and insulin levels several hours after feeding compared with the other sows. The authors concluded that sugar beet pulp as a source of fermentable dietary fibre stabilizes glucose and insulin levels and reduces physical activity in limited-fed sows several hours after feeding, possibly indicative of a prolonged feeling of satiety.

There is also indirect evidence that additional fibre, provided either as dietary inclusion or as foraging materials such as straw in the pen, reduces feeding motivation. Time spent either active, displaying stereotypies or both is reduced in restrictively-fed gilts or sows fed a high fibre diet (Robert et al. 1993, 2002; Brouns et al., 1994, 1995; Bergeron et al., 2000; Danielsen and Vestergaard, 2001; Zonderland et al., 2004; De Leeuw et al., 2004, 2005). For example, Bergeron et al. (2000) found that sows fed a control diet *ad libitum* spent less time displaying stereotypies than sows fed a very high fibre diet (4.5 kg/day (23% crude fibre) of a sugar beet diet), who in turn spent less time displaying stereotypies than sows fed a restricted control diet (2.5 kg/day). In contrast, some studies have found little or no effects of dietary fibre on stereotypies (2.75 kg/day (600 g sugar beet pulp/kg) of a high fibre diet, Whittaker et al., 1998, 1999).

Time spent active, displaying stereotypies or both, is also reduced in restrictively-fed gilts or sows provided with fibrous foraging materials (Spoolder et al., 1995; Stewart et al., 2008). For example in a factorial-designed experiment examining the effects of feeding level (1.8 kg (23 MJ)and 3.2 kg (40 MJ)/day fed in locked feeding stalls) and the provision of a foraging substrate (0 and 1.5 kg straw/sow), Spoolder et al. (1995) found that low fed sows spent more time manipulating substrates such as feed trough floor, bars and chains than high fed sows but that low fed sows provided with straw directed more of this activity towards straw than the feed trough floor, bars and chains. These results indicate that high levels of chain and bar manipulation in restrictively-fed sows can be prevented by providing straw which apparently acts as a foraging substrate. Thus increasing dietary fibre levels through providing access to a foraging substrate may have additional welfare benefits in terms of increasing environmental complexity and providing an outlet for exploratory behaviour (Lawrence and Terlouw, 1993; Spoolder et al., 1995).

There is limited evidence that high fibre diets may also affect sow aggression. One of the few investigations reported that high fibre diets reduced aggression and sham chewing in the second half of gestation in small groups of gilts and sows (Danielsen and Vestergaard, 2001). In contrast, Whittaker et al. (1999) found that provision of straw on the floor prior to feeding increased aggression during 2 h post-feeding in floor-fed sows throughout gestation. While overall skin lesions scores were unaffected, sows with straw had more vulva lesions. Stewart et al. (2008) also found increased aggression in sows in dynamic groups fed in an ESF when straw was provided in racks, but injury scores were unaffected. While limited access to straw may create competition and consequently aggression, Anil et al. (2006) suggested that a small quantity of straw may help to divert the attention of sows at mixing (Anil et al., 2006).

In addition to filling the gut and encouraging foraging behaviour, straw has also been shown to reduce stress and injury by providing grip for footing (Andersen and Bøe, 1999; Heinonen et al., 2013), insulation in winter or in cool climates (Barnett et al., 2001), and lying comfort (O'Connell, 2007; Durrell et al., 1997).

Therefore, on the basis of effects on feeding motivation, activity and stereotypies in restrictively-fed gilts or sows, additional fibre either through the inclusion of dietary fibre or the provision of fibrous foraging materials may prolong satiety between meals. De Leeuw et al. (2004; 2005) have shown the important role of fermentation of dietary fibre by the microflora in the hindgut on satiety but Meunier-Salaun et al. (2001) concluded in a review of the literature that incorporation of fibre in diets may reduce feeding motivation but only if the nutrient intake in fibrous diets meets the nutritional requirements of sows. As several authors have noted (e.g., Bench et al., 2013a), there is a need for further research to evaluate widely available and cheap fibre materials and feed grains in order to develop strategies to control nutrient intake of dry sows while feeding *ad libitum* because of the implications of hunger on sow welfare. Furthermore, providing additional fibre in the diet or access to a foraging substrate may have additional welfare benefits in terms of increasing environmental complexity and providing an outlet for exploratory behaviour, and consequently reducing the risk of the development of stereotypies in feed-restricted sows.

4.4. Feeding system

Drop feeding, in which feed is dropped on to the floor, either from an automatic feeder or manually, is one of the simplest and cheapest methods of feed delivery. Feed drops are normally spread to accommodate approximately 6-8 sows per feeder (Marchant-Forde, 2009). In addition, it often leads to variation between sows in feed intake with subordinate sows being underfed and exhibiting low weight gain (Edwards, 1992). Increasing the area on which feed is dispensed can minimize aggression and allow greater feed access for subordinate sows (Gonyou, 2005). Furthermore, multiple feed drops per day has been shown to reduce skin and vulva injuries and structural problems with feet and legs in gestating group-housed sows, although duration of agonistic behaviour was unaffected in young pre-pubertal gilts in groups (Schneider et al., 2007).

While floor feeding is competitive, accessing feeding stalls or electronic sow feeder (ESF) stalls also leads to competition between group-housed sows. For instance, in non-gated stalls, aggression often occurs during feeding periods and in ESF systems, queuing and vulva biting occur in accessing feeding stalls (Bench et al., 2013b). Nevertheless, in comparison to floor feeding, provision of feeding stalls, particularly full body length stalls, reduces aggression and plasma cortisol concentrations in the long term in group-housed gestating gilts (Barnett et al., 1992; Barnett, 1997; Andersen et al., 1999). In contrast, there appear to be no effects of feeding stalls on aggression or injuries up to 90 minutes after mixing (Barnett et al., 1993; Barnett, 1997).

The results of studies on the long term effects of provision on feeding stalls on injuries are contradictory: Barnett et al. (1992) and Barnett (1997) found no effects, but Andersen et al. (1999) found that feeding stalls, particularly full body length stalls, reduced skin injuries although full body stalls increased vulva bites. Even when feeding stalls are provided, it is of interest that floor space, either total or outside the feeder, affects aggression and plasma cortisol concentrations (Barnett et al., 1992; Barnett, 1997), highlighting the importance of floor space.

Apart from observations on skin and vulva injuries, no rigorous comparison of the effects of ESF and other feeding systems has been conducted. While confounded by floor space and other environmental variables, sows in pens with partial stalls have been shown to have lower levels of aggression and less skin injuries than sows in pens with ESF (Leeb et al., 2001; Durrell et al., 2002).

In addition to quantity of floor space, the quality of the space in terms of the physical barriers such as feeding stalls affect aggression, injury and stress in group-housed sows. It is important to provide sufficient space, both quantity and quality to allow the sows to establish a dominance hierarchy (Lindberg, 2001). Failure to do so may prolong aggression. Research has shown that reducing floor space within the range of 1.4 to 3.0 m^2/sow has been shown to increase aggression and stress in gestating gilts and sows.

4.5. Mixing pen

A number of authors have advocated the use of dedicated mixing pens that contain features that minimize sow aggression or the consequences of aggression on injury and stress by allowing avoidance by less aggressive sows (Edwards et al., 1993; Arey and Edwards, 1998; Barnett et al., 2001). However, there has been little research on this topic, particularly the long term effects when sows are subsequently placed in standard gestation pens.

Common suggestions in the literature and anecdotal observations are that the attributes of mixing pens that may reduce aggression include: straw or rice hulls and feed, which may provide a distraction (straw or rice hulls also allows a good foothold when fighting or fleeing); easy access to feed; absence of protruding objects or ridge edges that may damage sows (as in any pen); absence of tightly confined areas in which a sow could be cornered and unable to escape from an aggressive sow; and adequate space for sows to turn around and for two sows to easily pass side by side in all places.

Research mainly on gilts indicates that aggression at mixing is reduced by: modifying pen size and shape on the basis that pigs require a minimum space in which to fight; the use of masking odours on the basis that anosmic pigs show reduced aggression; sedation using pharmacological agents; and grouping after dark, on the basis that it is the ‘normal’ sleeping time, or providing feed *ad libitum* on the basis that restrictively-fed pigs may prefer to feed than fight (see review by Barnett et al., 2001). While aggressive displays may be initially inhibited, reducing space will increase stress (Barnett et al., 1992, 1993). There is some evidence that aggression in the short-term is reduced in rectangular pens compared to square (Barnett et al., 1993) or round pens (Wiegand et al., 1994). In relation to providing feed *ad libitum*, Barnett et al. (1994) found that the provision of *ad libitum* feed from a feeder for 24 and 48 h reduced aggressive interactions around feed delivered on the floor on day 2 and days 2 and 3 respectively, post-mixing. Unfortunately no observations were conducted outside the period in which feed was delivered on the floor but there were no treatment effects on injuries. Use of a solid visual barrier while not affecting frequency of fights after mixing has been shown to reduce frequency of aggressive interactions (see review by Marchant-Forde and Marchant-Forde, 2005). Furthermore, van Putten and van de Burgwal (1990) suggest that partitions reduce injuries in grouped-sows. In the long term, feeding stalls reduce aggression and stress at feeding (Barnett et al., 1992; Barnett, 1997; Andersen et al., 1999), however Barnett et al. (1993) and Barnett (1997) found no effects of feeding stalls on aggression or injuries up to 90 minutes after mixing. Nevertheless, feeding stalls may at times provide opportunities to escape from aggressive animals and further research on their effects over several days after mixing as the social order establishes may be useful. Therefore, the presence of visual barriers as with increased floor space may increase the opportunity for sows to visually isolate themselves from aggressive sows.

Results on the effects of boar presence on sow aggression and injuries are variable (see review by Marchant-Forde and Marchant-Forde, 2005). However, in a well-controlled study in which stocking density was also examined, the presence of a boar reduced aggression and skin injuries over 28 h after mixing (Docking et al., 2001).

Barnett et al. (2001) concluded that all or some of these above methods may only be effective in postponing aggression rather than reducing it. However, the aim when mixing sows should be to introduce the sows in a setting in which individuals can avoid aggressive ones when they want to with minimum risk to injury and stress, while also allowing the social hierarchy to quickly form.

One of the most obvious features of a mixing pen that will reduce aggression and stress is increased floor space. As discussed earlier, increasing floor space also reduces aggression and plasma cortisol concentrations in gestating gilts and sows (Barnett et al., 1992; Barnett, 1997; Weng et al., 1998; Remience et al., 2008; Hemsworth el al., 2013). Furthermore, the effects of reduced floor space on aggression and stress in grouped sows in the experiment by Hemsworth el al. (2013) was evident on the second day of grouping but not at 8 or 9 days after mixing, indicating that in static groups sows may adapt to reduced space. That is, the sow's requirement for space may be less once the group is established. Thus, research is required to examine the effects of increased space in a mixing pen on sow aggression and stress as well as the duration of housing in the mixing pen before floor space can be reduced without adversely affecting aggression and stress. Other important questions that need to be examined are whether changes in the design of the housing system following housing in the mixing pen, such as another feeding system or introduction to a dynamic group, initiate increases in aggression and stress.

Research on other features of mixing pens, such as visual barriers, feeding stalls, straw or bedding and *ad libitum* feed, on aggression, injuries and stress in both the short and long term (post-mixing pen) is also required.

4.6. Static and dynamic groups

Groups of sows can be managed as either a static group, in which the group composition remains stable after formation, or a dynamic group, in which sows are regularly removed from or introduced to the group. Static groups are mostly formed after weaning or mating, so that unfamiliar sows are mixed only once per gestation. On the other hand, unfamiliar sows in dynamic systems are frequently introduced to the group so that they experience between 3 and 12 times mixings per gestation (Marchant-Forde, 2009).

While some authors have suggested that problems with aggression may be greater in dynamic groups of sows (Arey and Edwards, 1998; Barnett et al., 2001), recent evidence does not necessarily support this interpretation. Durrell et al. (2002) found that aggression temporarily increased each time an unfamiliar group of sows was introduced to a dynamic group. Anil et al. (2006) studied pregnant sows housed in dynamic (mixed at 2-week intervals totaling about 100 sows), twice-mixed (2-week interval about 100 sows), and static groups of different sizes in pens of about 50 sows with an EFS (with one EFS per 50 sows) and found that skin injury scores were higher in the dynamic group than in the other groups both in general and 2 weeks after mixing. However, the housing treatment did not affect aggression, cortisol concentrations, farrowing performance and longevity. Strawford et al. (2008) found no differences in aggression, injuries and cortisol concentrations between sows in static (groups of 34 to 41 sows) and dynamic (mixed a 5-week intervals in groups totaling about 105 sows) groups with an EFS. The pens in the former study had non-bedded fully slatted flooring and provided a space allowance of 1.4 m^2/sow, while those in the latter study had non-bedded partially slatted flooring and provided a space allowance of 2.1 m^2/sow. While floor space allowance in study by Anil et al. (2006) appears sub-optimal and the comparison of the static and dynamic groups was confounded by group size in the study by Strawford et al. (2008), neither studies provide convincing evidence that sow welfare is adversely affected by dynamic groups in comparison to static groups.

4.7. Group composition

There is evidence that agonistic behaviour of individual sows may affect their welfare in groups. In a study in which sows in a group were classified on the basis of their ability to displace others in agonistic interactions (no, low or high success), it was found that sows of low success had higher basal concentrations of salivary cortisol and were more responsive to an ACTH challenge, both indicative of a chronic stress response, than sows of high or no success (Mendl et al., 1992). Furthermore, low success sows had lighter piglets than the other two categories of sows. Similarly, in comparison to sows of high or no success, socially intermediate sows show signs of stress, such as elevated cortisol concentrations and reduced natural T killer-cell activity and have lower farrowing rates and smaller litter sizes (Nicholson et al., 1993). In first or second parity groups mixed early after insemination, Verdon et al. (2013) found that sub-dominant sows (those that delivered less aggression than they received) had the highest cortisol concentrations early after mixing and gained less weight in pregnancy. While there were no differences in skin injuries early after mixing, dominant sows (those that delivered more aggression than they received) had less skin injuries while submissive sows (those that rarely delivered aggression) subsequently had the most skin injuries and the highest cortisol concentrations later in gestation.

There is also evidence that the composition of the group in terms of aggressiveness may affect the overall welfare of the group. Groups of young pigs of varying aggression (high and low), as assessed on the basis of the individual’s attack latency in a resident-intruder test, displayed less aggression immediately after mixing than grouping pigs of similar aggression (either high or low) (Erhard et al., 1997b). Furthermore, skin lesions were high in groups of high aggression. While mixing pigs pre-slaughter had little effects, D’Eath et al. (2010) found that mixed groups composed of aggressive pigs, predicted on the basis of previous skin lesions, had more carcass skin lesions and higher levels of plasma cortisol at slaughter.

In contrast to the young pig, there is limited evidence that the composition of the group in terms of aggressiveness may not affect the overall welfare of the group (M. Verdon and colleagues, personal communications). Using a test that had shown that the aggressive response of sows when introduced to stall with an unfamiliar sow in the adjacent stall was moderately predictive of the subsequent aggressive behaviour of sows in groups, it was found that grouping sows on the basis of either expected high or mixed aggression had no effect on aggression delivered or received, aggression index, injuries, cortisol concentrations or reproductive performance. This contrasts with previous studies in young immature pigs, however both the social behaviour and social experience of sows are markedly different to that of younger pigs. It appears that although sows vary in terms of individual aggressive characteristics, the tendency to show aggression is less important than the behaviour of others in the group. When fighting has significant costs, such as when sows are housed with older sows, otherwise aggressive sows may show flexibility in their use of aggression, opting out of aggressive interactions. Indeed, in studying the heritability of aggression, D'Eath et al. (2009) found that the pen effect explained a considerable part of the variation in the environmental component of aggression, implicating the role of group-mates on an individual's aggressive behaviour. Clearly further research is required on the effects of group composition in terms of aggression.

Thus while factors such as increased floor space and provision of feeding stalls reduce aggression and stress in group-housed sows, it is clear that a better understanding of the effects of the composition of the group, particularly the aggressive behaviour of individual sows, may have important implications for the welfare of the group as a whole. For example, the opportunity arises to assemble groups that perform well in terms of overall welfare based on the composition of the group if (1) the composition of the group in terms of aggressiveness of its individuals affects the overall levels of aggression, injury and stress in the group and (2) this behavioural characteristic is stable over time and/or is heritable.

Thus while group housing of sows allows all more freedom of movement, exploration and socialization, a few may suffer from excessive aggression, injuries and stress. Fraser (2013) suggests that in such cases, we need to decide what priority to attach to different classes of animals: the majority, the most vulnerable, the most productive, etc.

4.8. Genetics

Aggressive behaviour traits have been found to be heritable in Drosophila melanogaster, mice, adolescent humans and fighting bulls (see Turner et al., 2008). Recent research on groups of 10-13 growing pigs formed from two established groups has shown heritability estimates of 0.26 for receipt of non-reciprocal aggression and 0.38 for reciprocal aggression (Turner et al., 2008). Erhard et al. (1997a) suggested that differences between litters in attack latency in a resident-intruder test were sufficiently large to point to possible maternal or genetic effects. In a study of the genetic variation in aggressive behaviour of sows at mixing, Løvendahl et al.(2005) found that the heritability for severe aggressive behaviours performed during 30 minutes after mixing was intermediate ($h^2 = 0.24$) and lower for severe aggression received ($h^2 = 0.04$).

Obviously future research on sow welfare should place greater emphasis on genetics particularly the role of genetics on sow aggression in groups. Selection for reduced aggression in pigs is feasible and desirable, but as shown by D'Eath et al. (2009) other behaviours such as general activity and ease of handling may have a correlated response to some degree, with possible implications for animal production and welfare. Clearly further research on the implications of selecting for pigs of low aggressive behaviour is required.

4.9. Experience including rearing experience

It is widely accepted that like other basic behaviour, aggressive behaviour is strongly influenced by experience. In rats and mice, experience of social aggression leading to a victory increases the chances of attacks in subsequent encounters of the same kind (Kudryavtseva et al., 2004). Furthermore, the reward value of intra-specific aggression is indicated in studies in which winning or losing paired encounters can increase or decrease, respectively, subsequent attack rates (see review by Potegal, 1976). It is suggested that the reduction in attack initiation occurring after defeat is likely an avoidance effect due to punishment. Since in many of these paired encounters studies, there was nothing contingent on winning, the increases in attack rate in victorious animals suggest that successful attack may be intrinsically rewarding. Indeed it has been shown in operant conditioning experiments, in which animals perform operant responses to provide themselves with intraspecific attack opportunities, that the animals were actively seeking out targets, rather than fighting to remove the presence of another (see review by Potegal, 1976). It has also been argued that animals in paired encounters learn to avoid pain inflicted by their opponents by attacking them first.

Familiarity may affect aggression at mixing. The total time unacquainted pigs spend fighting following mixing is up to 97 times more than familiar pigs (Li and Johnston, 2009). Kennedy and Broom (1996) found that aggression received by pigs individually introduced to groups was reduced when the original group of pigs had previously received 5 days of auditory or olfactory contact with the individual. Arey (1999) found that fights were rare between sows that had been housed together 2, 4 or 6 weeks earlier. Durrel et al. (2003) examined the effects of introducing small groups of mixed-parity sows to a larger established group either directly, or after 5 weeks of housing together and found that aggression was reduced both between newly introduced sows and between newly introduced sows and resident sows when the introduced groups were familiar with each other. Other studies have also demonstrated lower levels of aggression in levels among sows that are familiar with one another (Puppe 1998; Olsson and Samuelsson 1993). In contrast, Strawford et al. (2008) found no effect of familiarity on aggression. These sows were separated for a minimum of four weeks while in the farrowing crates, and one week during breeding and the authors commented that the percentage of familiar pigs in pens was small.

Thus while recent familiarity may reduce sow aggression on mixing, unfamiliar sows will fight when mixed. Optimizing factors such as floor space and other design features, such as barriers, as well as providing access to important resources, such as feed, water and a lying area, are obviously important in reducing aggression at mixing and subsequently. Furthermore, mixing sows or a proportion of sows that have been housed together in the previous gestation may reduce aggression at weaning or post-insemination.

There is considerable evidence with many species that, while the prenatal and neonatal (rearing) periods are important in behavioural development, learning can rapidly and strongly occur during the adolescent period and may even reverse or enhance some of the earlier environmental effects. Social skills for later life are learnt particularly in adolescence and social experiences with other and older animals may affect stress responsiveness. For example, contact with adolescent females as well as contact with adult females and males appears particularly important for male guinea pigs. Lurzel et al. (2010) found that housing individually during adolescence rather than in mixed-aged and mixed-sex groups resulted in males being more aggressive when introduced to an unfamiliar colony (mixed aged and mixed-sex group): some males adapted but some had major difficulty adapting and had to be removed to avoid ill health and death. This research highlights the importance of the adolescent period on social skills and raises possible implications for the social behaviour of sows. Although the guinea pig has different life history and males were studied, the life history of wild European boar involves matriarchal groups and thus interactions with older sows may be important in developing social skills in the female pig.

Recent Danish research (Rasmussen, 2012) has studied the effects of this so-called ‘socialization’ during rearing on pregnant gilts in groups. While exposure to sows was confounded by mixing during rearing, socialized gilts in their first pregnancy in dynamic groups spent more time using the resting areas occupied by older sows than non-socialized gilts. That is, the socialized gilts appeared to be better integrated in the social structure of the main group of sows. The full effects of socialization may not be revealed without studying the effects of social contact with unfamiliar gilts and sows during the entire adolescent period. Furthermore, these effects of socialization need to be studied for socialized females being mixed with other unfamiliar socialized mated gilts and mated socialized sows and compared to controls (i.e., ‘unsocialized’ gilts and sows).

4.10. Stage of reproductive cycle at mixing

Most studies on the effects of group housing have examined mixing once pregnancy has been confirmed, which generally occurs after 30 days of pregnancy. Few studies have examined mixing during earlier stages of pregnancy, or even before insemination.

Algers et al. (2007) suggest that housing sows in stalls around the time of oestrus may cause stress and frustration because they cannot adequately express their sexual behaviour. However, there is evidence that group housing, while facilitating the sexual behaviour of dominant sows, may depress the sexual behaviour of subordinate sows. Dominant sows show more sexual behaviour, particularly mounting other sows, than lower ranking sows (Pedersen et al., 1993). Furthermore, dominant sows mount lower ranking ones, increasing the risk of leg injuries to both, whereas the subordinate sows seldom mount dominant sows. Dominant sows in pairs showed greater attraction to the boar and receptivity than the subordinate sows while sows housed individually were intermediate (Pedersen et al., 2003), suggesting that group housing may facilitate the sexual behaviour of dominant sows while suppressing that of subordinate sows. Stall or group housing does not affect oestrus detection rate or duration of oestrus when weaned sows receive high levels of boar stimulation but group housing delayed the onset of oestrus and increased the variation in the onset of oestrus (Langendijk et al., 2000).

There is limited evidence from unpublished Danish research that the sexual behaviour of group-housed sows may lead to injury and reproductive failure. Research on housing post-weaning at two commercial farms (Hansen, 2000b) indicates that housing sows on partially slatted floors between two rows of feeding and insemination stalls, while not affecting reproductive performance, increased prevalence lameness in comparison to housing on deep litter straw between two rows of feeding and insemination stalls. The effect was most pronounced at the commercial farm with the lower floor space allowance (3.3 vs. 4.2 m^2/sow). Furthermore, housing in groups on litter post-weaning with a floor space allowance of 3-3.9 m^2/sow in comparison to individual stalls has been found to reduce total born litter size by 0.3 piglets but not farrowing rate (Hansen, 2000). In contrast, Hansen (2003b) found no effects of housing weaned sows individually in sow stalls or in groups of 10-12 sows with 3-4 m^2/sow on reproductive performance, while Hansen (2003a) found that housing weaned sows housed individually in sow stalls reduced farrowing rate but not litter size in comparison to housing weaned sows in groups of 7-10 sows with 3.6-5.4 m^2/sow. Sows in the study by Hansen (2000) were inseminated in the group pen while those in the study by Hansen (2003a) were checked for oestrus and inseminated in feeding/insemination stalls in which they had permanent access. Housing around the time of oestrus detection and insemination may also affect reproduction. Confining parity 2 and 3 sows but not older sows in feeding/insemination stalls during oestrus detection and insemination and for about 2 hours after insemination increased farrowing rate in comparison to immediately releasing sows back into their weaned group (Fisker, 2003). In contrast, confining parity 2 and 3 sows but not older sows in feeding and insemination stalls in group pens during oestrus detection and insemination reduced litter size in comparison to removing sows in small groups from their group pen to another pen for oestrus detection and insemination (Fisker, 2005). While housing sows from weaning until 7 days after weaning in groups with free access to feeding/insemination stalls or in stalls from 3 to 7 days after weaning did not affect reproductive performance, a higher proportion of sows were culled up until 7 days after weaning when housed in groups from 3 to 7 days after weaning (Hansen and Jensen, 2005a).

While the treatment effects varied and pen design features such as floor space and group size varied between and within these studies, these unpublished Danish results overall suggest that increased floor space and stall housing to protect oestrous sows from the courting and mounting behaviour of other sows at the time of oestrus detection and insemination or for several hours after insemination reduces risks to injury and reproductive performance of group-housed weaned sows. However, clearly further research is required to clarify the effects of group housing from weaning and around oestrus detection and insemination.

Housing post-weaning is an important period that has implications for both sow welfare and reproductive performance. Some issues are similar to those for sows grouped after insemination, such as aggression associated with grouping unfamiliar sows and pen design, such as floor space and feeding system. Other issues are distinct to this period, such as the consequences of housing around insemination on stress and potential injuries specifically arising from sows displaying sexual behaviour. A better understanding of pen design, in terms of increased floor space and a non-slip floor, and individually housing sows during the period in which they display courtship and mount and are mounted by others, may be useful in minimizing injury to sows through courtship and mounting and thus reduce stress.

There is limited evidence that the stage of the reproductive cycle in which sows are mixed may affect aggression. There is an early report that aggression between sows which were mixed after weaning was greater than that for sows mixed while lactating (Olsson and Samuelsson, 1993). Sows are more aggressive, have higher cortisol concentrations and more skin injuries in large pens with deep litter and external feeding stalls when mixed in the first week after insemination than 5 weeks post-insemination (Hemsworth et al., 2006; Stevens et al., unpublished data). Hemsworth et al. (2006) have suggested that based on studies in rodents (Fraile et al., 1987; Kohlert and Meisel, 2001) that aggressive behaviour of sows may decline as progesterone concentrations peak in the pig around day 16 of pregnancy and remain elevated until just prior to parturition. This finding that sows may be more aggressive when mixed early after insemination agrees with those of Strawford et al. (2008). Despite aggression immediately after grouping and skin lesions during 10 weeks after grouping being similar, Strawford et al. (2008) found that the frequency of aggression at the ESF during 10 weeks after grouping was higher for sows mixed in both static and dynamic groups at 2-9 days post-insemination than at 37-46 days post-insemination. While the latter sows had higher salivary cortisol concentrations post-mixing, this comparison is confounded by stage of gestation as total cortisol concentrations increase throughout gestation (Barnett et al., 1985; Hay et al., 2000). In contrast to the findings of Strawford et al. (2008), Van der Mheer et al. (2003) found that skin injuries scores during gestation were lower when introduced immediately after insemination than when sows were introduced into dynamic groups with ESF without protection at 15 and 29 days after insemination.

In relation to the effects of aggression and possibly stress when sows are mixed soon after insemination, Li and Gonyou (2013) found that sows mixed at 7-9 days post-insemination in static or dynamic groups with ESF had a lower farrowing rate than those mixed in similar conditions at 35 days post-insemination. Hopgood et al. (2012), reported that farrowing rates were lower for sows mixed at 3 days post-insemination compared to sows mixed at 14 and 35 days post-insemination following stall housing from weaning, although the least frequency of fighting was seen at 14 days post-insemination. Given this limited evidence and the interest in increasing the use of group housing of sows, it is important to understand the effects of stage of gestation at mixing on sow welfare and reproduction.

In reviewing the literature on the effects of grouping sows at weaning, Algers et al. (2007) concluded, based on several unpublished field studies conducted in the 2000s by the Danish Meat Association, that there is no unambiguous evidence that group housing from weaning to mating results in reduced reproduction. Unpublished Danish research (Nielsen, 1999) suggests that there are no effects of grouping restrictively-fed sows in dynamic groups early after insemination rather than 4 weeks after insemination on farrowing rate or litter size. But other unpublished Danish research (Fisker, 1995, 1999) suggests that grouping restrictively-fed sows in static groups at weaning or early after insemination rather than 4 weeks after insemination reduces total born piglets (by 0.6 and 0.5 piglets per litter, respectively) but did not affect farrowing rate. In a recent review of the literature on the effects of factors in early pregnancy that affect reproduction of group-housed sows, Spoolder et al. (2009) reported that it is not easy to conclude on the best time of grouping for optimal reproductive performance. They suggested that the variable results reported in the literature indicate that other factors such as the type of housing system and type of sow studied may be responsible for this ambiguity. However, Spoolder et al. (2009) recommended that stress should be avoided to minimize reproductive failure, especially in weeks 2–4 of pregnancy in which the two sensitive reproductive events occur, the period of attachment of embryos to the uterine wall (days 11–16) and the period shortly thereafter, because in this period, the so-called ‘maternal recognition of pregnancy’ takes place and many associated hormonal changes occur.

A number of studies on the stage of gestation when mixed indicate that challenges associated with aggression and stress at mixing are greater early after insemination and thus research examining ways of reducing risks to sow welfare and productivity associated with grouping need to focus on this stage of the reproductive cycle when challenges may be greater. Furthermore, with the widespread international move away from stall housing of sows, there is likely to be an increasing use of grouping sows at weaning, as occurs in some countries such as the UK. A better understanding of pen design, particularly in terms of floor space, flooring and protection of oestrous sows from mounting by others, is important in minimizing injury, stress and reproductive failure.

4.11. Parity

Surprisingly, there has been little research on the effects of parity on sow welfare. Older sows mixed in static and dynamic groups with EFS have more total injuries than younger sows (Hodgkiss et al., 1998; Anil et al., 2005; Strawford et al., 2008), with Strawford et al. (2008) reporting that 4th parity or older sows are involved in more aggressive interactions than younger sows. In contrast, Jansen et al. (2007) found no effects of parity on total aggressive interactions when sows were mixed in groups in mid gestation in pens with drop feeders. Unpublished Danish research (Hansen and Jensen, 2005b) suggests that while sorting sows into groups of 15-23 at weaning according to light or heavy body weight (mean of 209 and 255 kg respectively) does not affect mounting or aggression, total born piglets is lower in unsorted light weight sows than sorted light weight sows.

4.12. 'Stockmanship'

Research, initially in the pork industry and subsequently in other livestock industries, has stimulated considerable research on the effects of the stockperson on animal welfare and productivity. As indicated in the review of this topic of stockmanship by Hemsworth and Coleman (2011), there are three main lines of evidence demonstrating the impact of stockpeople on the welfare of pigs and other farm animals: handling studies in controlled experimental conditions, observations in commercial settings and intervention studies in commercial settings. Conditioning and habituation to humans, occurring both early and later in life, are the most influential factors affecting the behavioural responses of farm animals to humans. The results of handling studies in the laboratory and intervention studies on farms, using cognitive behavioural training of stockpeople, on the relationships between stockperson attitudes, stockperson behaviour, animal behaviour and stress physiology provide evidence of causal relationships between these variables. Furthermore, this research provides a strong case for introducing stockperson training courses in the livestock industries which target stockperson attitudes and behaviour.

The training or intervention procedure used as an experimental tool in this research in the pork industry has been commercialized for the pork industry, and is called "ProHand" ("Professional Handling Program"). The ProHand approach has been extended into a package for dairy stockpeople and, following recent research at abattoirs, into packages for pig and red meat abattoir stockpeople in Australia. Training packages based on the ProHand principles have been developed in Europe as part of the EU 6th Framework for stockpeople in the pig, poultry and cattle industries. Details of these training programs are described by Hemsworth and Coleman (2011). This body of research highlights the importance of the stockperson on animal welfare and provides the evidence for pronouncements such as that in British Codes of Recommendations for the Welfare of Farm Livestock (Ministry of Agriculture, Fisheries and Food, 1983) that "Stockmanship is a key factor because, no matter how otherwise acceptable a system may be in principle, without competent, diligent stockmanship, the welfare of animals cannot be adequately catered for".

Apart from effects of poor handling on stress, poor stockperson attitudes are likely to lead to reduced commitment to the surveillance of, and the attendance to, welfare and production issues (Hemsworth and Coleman, 2011), which is likely to greater consequences in group housing than stall housing situations.

There is a clear on-going need for the livestock industries to train their personnel to effectively care for and handle their stock. The role and impact of the stockperson should not be underestimated: to do so will seriously risk the welfare and productivity of livestock. Indeed it is possible that the stockperson may be the most influential factor affecting animal handling, welfare and productivity. Furthermore, it is likely that in the near future both the livestock industries and the general community will place an increasing emphasis on ensuring the competency of stockpeople to manage the welfare of livestock (Hemsworth and Coleman, 2011). While welfare monitoring schemes are likely to improve animal welfare, the impact of such schemes will only be realized by recognizing the limitations of stockpeople, monitoring 'stockmanship' and providing specific stockperson training to target key aspects of stockmanship (Hemsworth et al., 2009).

5. Conclusion on group housing of sows

5.1. Space

The literature on gilts and sows indicate that space can affect aggression, injuries and stress physiology. However, the space allowance at which sow welfare, based on aggressive behaviour, injuries, cortisol concentrations, immunological responsiveness and farrowing rate, is compromised is difficult to assess from these results, except that 1.0 m^2/gilt is insufficient in gilts and 1.4 m^2/sow is insufficient in sows. Clearly, further research is required to examine the effects of space allowance in the range of 1.8 to 2.4 m^2/sow in more detail, with particular attention given to the effects of space early post-insemination because this is the period when effects on aggression, stress, and reproduction are likely to be most pronounced. It needs to be recognized that in addition to quantity of floor space (amount), the quality (configuration, including physical and visual barriers) is also likely to affect sow aggression.

5.2. Group size

While the literature on effects of group size on aggression and injuries are contradictory, there is no evidence that large group sizes of 20 to 80 affect stress or reproductive performance. However there is evidence in one experiment that aggression but not injuries increases in larger groups, while another indicates that injuries but not aggression increases in larger groups. Other factors such as floor space and competition for feed or access to feeding areas may have a greater impact on aggression, injuries, stress and reproduction than group size.

5.3. Feeding system

While floor feeding is competitive, accessing feeding stalls or electronic sow feeder (ESF) stalls also leads to competition between group-housed sows. Provision of feeding stalls, particularly full body length stalls, reduces aggression at feeding and stress in group-housed gestating gilts, but the effects on injuries in gilts and sows are less clear. Apart from observations on skin and vulva injuries, no rigorous comparison of the effects of ESF and other feeding systems has been conducted.

5.4. Nutrition

Stereotypies have been shown to develop in feed-restricted sows, but while few studies have been specifically conducted, there is no consistent evidence of increased aggression, stress or injuries in feed-restricted sows. There is limited evidence that a lack of energy in the diet may contribute to the development of stereotypies.

On the basis of effects on feeding motivation, activity and stereotypies in restrictively-fed gilts or sows, additional fibre, provided either as dietary inclusion or as foraging materials, may prolong satiety between meals but only if the nutrient intake in fibrous diets meets the nutritional requirements of sows. Recent reviews highlight the need for further research to evaluate widely available and cheap fibre materials and feed grains in order to develop strategies to control nutrient intake of dry sows while feeding *ad libitum* because of the implications of hunger on sow welfare. Furthermore, providing additional fibre in the diet or access to a foraging substrate may have additional welfare benefits in terms of increasing environmental complexity and providing an outlet for exploratory behaviour, and consequently reducing the risk of the development of stereotypies in feed-restricted sows.

5.5. Mixing pen

The aim of a mixing pen should be to introduce the sows to be grouped in a setting in which individual sows can avoid aggressive ones when they want to with minimum risk to injury and stress, while also allowing the social hierarchy to form. A mixing pen with increased floor space and barriers, perhaps through increased opportunities to provide visual separation from others sows, is likely to reduce aggression at mixing while also enabling the social hierarchy to form. Further research is required to examine the effects of features of mixing pens, such as floor space, visual barriers, feeding stalls, straw or bedding and *ad libitum* feed, on aggression, injuries and stress in both the short and long term.

5.6. Group composition

While factors such as increased floor space and provision of feeding stalls reduce aggression and stress in group-housed sows, a better understanding of the effects of the composition of the group, particularly the aggressive behaviour of individual sows, is likely to have important implications for the welfare of the group as a whole. For example, the opportunity arises to assemble groups that perform well in terms of overall welfare based on the composition of the group if (1) the composition of the group in terms of aggressiveness of its individuals affects the overall levels of aggression, injury and stress in the group and (2) this behavioural characteristic is stable over time and/or is heritable. Furthermore, there may be merit in ensuring that a proportion of sows that have been housed together in the previous gestation are mixed wherever possible, since sows that have been housed together in the previous gestation are likely to fight less when grouped at weaning or post-insemination.

Thus while group housing of sows allows all more freedom of movement, exploration and socialization, a few may suffer from excessive aggression, injuries and stress. In such cases, we need to decide what priority to attach to different classes of animals: the majority, the most vulnerable, the most productive, etc.

5.7. Static and dynamic groups

While there few studies that have specifically compared the two, there is no convincing evidence that sow welfare is adversely affected by dynamic groups in comparison to static groups. Getting other features right, such as pen design in terms of floor space, feeding system, etc., may be more important than whether the group is static or dynamic.

5.8. Genetics

Aggressive behaviour in pigs has been found to be moderately heritable. Obviously future research on sow welfare should place greater emphasis on genetics particularly the role of genetics on sow aggression in groups. Selection for reduced aggression in pigs is feasible and desirable, but further research on the implications of selecting for pigs of low aggressive behaviour is required.

5.9. Experience

Sows that have been housed together in the previous gestation may fight less at weaning or post-insemination, but unfamiliar sows will fight when mixed and thus design features at mixing should be optimized. Based on studies with other social species, social contact with unfamiliar gilts and sows during the adolescent period may affect subsequent social skills. Further research on these so-called socialization effects on the long-term social behaviour and stress of sows in groups is warranted.

5.10. Stage of the reproductive cycle at mixing

It appears that the challenges associated with aggression and stress at mixing are greater early after insemination than when mixed later. Thus research examining ways of reducing risks to sow welfare and productivity associated with grouping need to focus on this early stage of the reproductive cycle. Furthermore, with the widespread international move away from stall housing of sows, there is likely to be an increasing use of grouping sows at weaning, as occurs in some countries such as Denmark and the UK. A better understanding of pen design, particularly in terms of floor space, flooring and protection of oestrous sows from mounting by others, is important in minimizing injury, stress and reproductive failure in sows grouped at weaning.

5.11. Stockmanship

There is a clear on-going need for the livestock industries to train their personnel to effectively care for and handle their stock. The role and impact of the stockperson should not be underestimated: to do so will seriously risk the welfare and productivity of livestock. Indeed it is possible that the stockperson may be the most influential factor affecting animal handling, welfare and productivity. Furthermore, it is likely that in the near future both the livestock industries and the general community will place an increasing emphasis on ensuring the competency of stockpeople to manage the welfare of livestock (Hemsworth and Coleman, 2011). While welfare monitoring schemes are likely to improve animal welfare, the impact of such schemes will only be realized by recognizing the limitations of stockpeople, monitoring ‘stockmanship’ and providing specific stockperson training to target key aspects of stockmanship (Hemsworth et al., 2009).

6. Overall conclusions

While group housing provides some obvious welfare advantages for sows, such as more freedom of movement, exploration and socialization, some animals may suffer from excessive aggression, stress and injuries. Unfamiliar sows will generally fight when mixed but this is necessary to establish a dominance hierarchy particularly in situations of limited resources.

Factors that have been shown to impact upon sow welfare in group-housed sows have been discussed in this review. The greatest influence appears to be space allowance. Pigs have a requirement for physical space to stretch and exercise. Space may also be needed for body care or grooming and assisting in thermoregulation when hot. In addition to spatial requirements for physical size and basic movement, pigs need to access key resources such as feed, water and lying space. They are also motivated to interact with other sows and to explore (particularly if hungry). Thus they need space not only to access the resources but also if necessary to distance themselves from others, including when accessing these resources. In addition to quantity of floor space, the quality of space is also important: spatial separation between sows can also be provided with visual or physical barriers and stalls. Thus optimizing factors such as floor space and other design features, such as barriers as well as providing access to important resources such as feed, water and a lying area, appear to be important in reducing aggression and stress at mixing and beyond. Further research is required to examine the effects of space allowance in the range of 1.8 to 2.4 m^2/sow in more detail.

Since the period immediately post-mixing has the most pronounced effects on aggression and stress, well-designed mixing pens offer the opportunity to reduce aggression, injury and stress while allowing the social hierarchy to quickly form before animals are moved to perhaps a less extensive group housing system for the remainder of gestation. Thus, research is required to examine the effects of increased space in a mixing pen on sow aggression and stress as well as the duration of housing in the mixing pen before floor space can be reduced without adversely affecting aggression and stress. The effects of other changes in the design of the housing system following the mixing pen, such as another feeding system or introduction to a dynamic group, on aggression and stress require examination.

As with space, feeding system can affect aggression and stress, but the design of these systems in terms of stall length and ease of access to and from stalls, is likely to affect sow welfare. Furthermore, since hunger is likely to lead to competition for feed or access to feeding areas, opportunities to prolong satiety between meals through higher feeding levels and provision of additional fibre in the diet or access to a foraging substrate should be examined because of their implications on stereotypies and aggression.

Genetic selection on reduced aggression has the potential to reduce aggression. Developments in understanding the opportunity to genetically select against aggressiveness and its broader implications on sow welfare and productivity should be closely followed and utilized if feasible and practical to minimize sow aggression.

Exposing juvenile gilts to sows (socialization) may facilitate more rapid and safe development of the social hierarchy when these females are subsequently mixed with unfamiliar females in later life. The potential effects of socializing juvenile gilts on aggression, injuries and stress of sows mixed in later life is clearly warranted.

There are additional challenges when mixing sows at weaning and consequently a better understanding of mixing pen design, including flooring and protection of oestrous sows from mounting by others, as well as strategies such as those mentioned above (dietary and environmental manipulations), is important in minimizing injury, stress and reproductive failure in these sows.

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