The Productivity and Behaviour of Sows and Piglets Housed in Farrowing Pens with Temporary Crating or Farrowing Crates

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Abstract

Pen-based alternatives to farrowing crates have been researched for decades, in an effort to improve the welfare of farrowing and lactating sows. However, high piglet mortality, and a lack of commercially-relevant studies, has been a barrier to the acceptance of these systems in the pork industry. The purpose of this thesis was to compare the performance and behaviour of sows and piglets in farrowing pens with temporary crating, and in farrowing crates, in a commercial setting. In the first study, sows were housed in either a farrowing crate from 5 days pre-farrowing until weaning at 28 days; or in a pen where sows were crated from 3 days pre-farrowing until the 4th day of lactation. The farrowing system (crate or pen) from which a sow was weaned had no effect on subsequent reproductive performance. However, pre-weaning piglet mortality was significantly higher in pens (10.2%) than in crates (6.1%).

Sow and piglet behaviour was studied during the first 6 days post-farrowing in the second study. Sows in crates were confined throughout this observation period, whereas sows in pens were crated for days 1 – 3 post-farrowing and loose in the pen during days 4 – 6 post-farrowing. There was no difference between systems for the amount of time sows spent lying or standing during days 1 – 6, though sows in pens were more active once they were loose. Penned sows touched and investigated their piglets more once they were loose, compared to when they had been crated. There were few differences in piglet behaviour between farrowing systems.

The influence of the birth and rearing location (crate or pen) on gilt behaviour was examined in the third study. Gilts were identified as having been born and reared in a farrowing crate or in a pen. Gilts and their piglets were observed during the first three days after giving birth in the system they were born and reared in, or in the system they were not born and reared in. Gilts born and reared in pens with temporary crating touched and vocalised towards their piglets more than gilts born and reared in farrowing crates, irrespective of whether they farrowed in a crate or a pen. This finding has implications for the transmission of maternal behaviour.

The associations between sow behaviour, gilt behaviour and piglet behaviour were compared in farrowing crates and pens with temporary crating using the data of the second and third study. Some associations between sow and piglet behaviour changed when the sow was no longer confined in a crate. This finding could be the link that explains differences in the later behaviour of gilts that were reared in different systems. Future studies should focus on the transition period between a sow being crated and then let loose in a pen, to improve sow and piglet welfare in these systems.

Declarations

This thesis contains no material that has been accepted for a degree or diploma by the University or any other institution. To the best of my knowledge no material previously published or written by another person has been used, except where acknowledgement has been made in the text.

This thesis has been written with chapters formatted as papers for publication. Therefore there is some repetition of methods. Each chapter contains a full discussion and a complete list of references. The final general discussion chapter provides a succinct discussion of the key findings of this thesis. The published and submitted manuscripts include supervisors as co-authors; however for each chapter, I developed the experimental design, carried out data collection and performed data analysis, with the final manuscript being written with the direction of the co-authors.

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PhD Thesis, Massey University, New Zealand

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List of Abbreviations

NAWAC = National Animal Welfare Advisory Committee

ACTH = Adrenocorticotrophic hormone

HPA = Hypothalamic Pituitary Adrenal (axis)

ABN = Arched-back nursing

LG = Licking and grooming

C = Farrowing crate

P = Pen with temporary crating

PWM = Pre-weaning piglet mortality rate, expressed as a percentage

$PGF_{2\alpha}$ = Prostaglandin $F_{2\alpha}$

WSI = Wean to service interval

ADG = Average daily gain (birth to weaning)

AM1 = Observation session between 0800 – 0845

AM2 = Observation session between 0920 – 1100

PM1 = Observation session between 1230 – 1445

PM2 = Observation session between 1520 – 1600

CC = A gilt born and reared in a crate, which farrowed in a crate

CP = A gilt born and reared in a crate, which farrowed in a pen

PC = A gilt born and reared in a pen, which farrowed in crate

PP = A gilt born and reared in a pen, which farrowed in a pen

C1 = Crate, Period 1 (days 1 – 3 post-farrowing)

C2 = Crate, Period 2 (days 4 – 6 post-farrowing)

P1 = Pen, Period 1 (days 1 – 3 post-farrowing)

P2 =Pen, Period 2 (days 4 – 6 post-farrowing)

P_{day} = P value for the main effect of the day of observation

P_{system} = P value for the main effect of the farrowing system (crate or pen with temporary crating)

P_{born} = P value for the main effect of the location where a gilt was born and reared (crate or pen with temporary crating)

P_{farrow} = P value for the main effect of the location where a gilt farrowed (crate or pen with temporary crating)

Chapter 1

General introduction

Farrowing crates have been commonplace on indoor pig farms in New Zealand since their introduction in the 1960s (Barugh, 2015). Whilst their design has since been modernised, the fundamental purpose of the crates used today remains unchanged. Farrowing crates confine sows during the farrowing and lactation period in the interests of the piglets. The crate is designed to limit a sow's movements to standing, sitting, and lying, and to encourage the sow to lie down slowly, giving piglets time to move out of the sow's way. There are concerns that this restriction compromises sow welfare due to poor mobility, limited interaction with piglets, and a lack of enrichment. These deficiencies have led to criticism of farrowing crates from the perspective of the sow's welfare.

Over the last 20 to 30 years, indoor alternatives to farrowing crates have been investigated and developed to address the perceived welfare issues experienced by sows in crates (Cronin, 2010). These alternatives are based on a pen design, with the objective of reducing or eliminating the confinement of sows in crates throughout farrowing and lactation in order to improve the sow's welfare. The removal of the crate from a farrowing system has negative consequences for piglet welfare as it is widely accepted that piglet mortality in pen-based farrowing systems is higher than in farrowing crates (Cronin, 2010; Morrison et al., 2013). The proposed alternatives to crates must be economically viable and suitable for a commercial setting in terms of practicality and stockperson safety.

A key indicator used to compare different farrowing systems is pre-weaning piglet mortality as this single parameter provides information about economics, performance and welfare. Similar levels of piglet mortality can be achieved in crate and pen-based farrowing systems (Morrison and Baxter, 2013), however, piglet mortality rates are not consistent across different studies, and there is a poor understanding of why inconsistent performance occurs within and between different pen designs. If pre-weaning piglet mortality is higher in pen-based systems than it is in crate-based systems, then piglet welfare will be compromised to a greater degree. This raises the issue of balancing the needs of the sow and the piglets in such a way that net welfare is improved. Currently, the overall welfare benefits of pen-based alternatives to crates are largely unproven in a commercial setting (FAWC, 2015). This is a key reason why universal commercial adoption of non-crated farrowing systems has not occurred (Baxter et al., 2011).

The motivation for developing alternatives to farrowing crates has emerged from concerns about sow welfare. These alternatives should therefore demonstrate an actual improvement (as opposed to a perceived improvement) in the welfare of the sow, but not at the expense of piglet welfare. The physical and behavioural needs of sows during farrowing and lactation have been well documented in natural and semi-natural environments (Stolba and Wood-Gush, 1984, 1989; Algers and Jensen 1990). This research has guided the development and design of indoor farrowing systems that reduce or eliminate the confinement of sows in crates, with the objective of improving sow welfare. The current position of New Zealand's National Animal Welfare Advisory Committee (NAWAC) is that farrowing crates do not provide for every behavioural need of sows (Anon, 2016). However, higher welfare alternatives to farrowing crates, such as farrowing pens, result in higher piglet mortality, thus farrowing crates currently achieve the best welfare outcome for piglets, and the best *net* welfare outcomes for sows and piglets when compared to alternatives (Anon, 2016).

Few studies have explored the relationship between the farrowing environment, the behaviour of the sow, and the behaviour of her piglets. The interactions between a sow and her litter guide the behavioural development of piglets, and can positively influence their behaviour post-weaning (Oostindjer et al., 2011). The level of maternal care experienced in early life can even influence behaviour in the longer term, which may have implications for the future maternal behaviour of adult female offspring (Champagne, 2011). This could have wider significance for gilts when they first give birth.

Thesis outline

This thesis focuses on four research topics each presented in a chapter which is a stand-alone paper. Each chapter has its own introduction, materials and methods, results, and discussion. There is some overlapping in methodologies described in each chapter. Some of these chapters have been published, others have been submitted to a journal for consideration. Each chapter begins with a review of the relevant literature. A more in depth literature review is presented in Chapter 2 of this thesis.

Investigations into alternative farrowing systems have identified many gaps in knowledge. One of these is the lack of large-scale experimental data to reflect the conditions of a commercial setting. Thus the primary objective of this thesis was to compare the behaviour and performance of sows and piglets in farrowing crates and in pens with temporary crating, in a commercial setting. The following specific objectives were developed:

- In Chapter 3, sow and piglet performance in farrowing crates and in pens with temporary crating was compared using a number of key performance indicators. These included the subsequent reproductive performance of sows, piglet mortality, and the causes and timing of piglet death in the two farrowing systems.

- The next study, in Chapter 4 compared sow and piglet behaviour and posture in farrowing crates and in farrowing pens with temporary crating. Sows in both farrowing systems were observed for the first 6 days post-farrowing. During this observation period, sows in farrowing crates were confined throughout, and sows in pens were observed whilst crated on days 1, 2 and 3 and when loose on days 4, 5 and 6.

- Chapter 5 is a study of transgenerational behaviour in gilts. The effect of early life experience on the behaviour and performance of gilts during their first parity was investigated. Four treatment groups were identified: Gilts born and reared in crates which farrowed in crates (CC); gilts born and reared in crates which farrowed in pens (CP); gilts born and reared in pens which farrowed in crates (PC); and gilts born and reared in pens which farrowed in pens (PP). These gilts and their piglets were observed for the first three days post-farrowing whilst still confined in crates.

- In Chapter 6, the association between the behaviour of sows and gilts and their piglets, using the data from Chapters 4 and 5, was investigated in the two farrowing systems to determine how they may influence each other's behaviour.

The methodology for Chapter 5 was the same as in Chapter 4. Behavioural observations were carried out during days 1 – 6 post-farrowing. In the midst of data collection, farm management decided to extend the period of temporary confinement in the pen system from 3 days post-farrowing to 7 days post-farrowing. Their reason for this related to concerns about piglet mortality, thus their solution was to confine the sow for longer so that piglets were older and more robust when the sow was let out of the temporary farrowing crate. Observations of gilts in one of the experimental groups (CP) were affected by this decision, and behavioural observations were collected to day 3 post-farrowing only. Thus, gilts in this group were not observed once they had been let out of their temporary crate. If they had been observed after being let loose from the crate, this would have occurred on days 8, 9 and 10 post-farrowing which would have confounded any comparison of behaviour, especially in the case of the piglets, as they would have been older at the time of observation. For this reason, only the first three days post-farrowing were analysed for all treatment groups in Chapter 5.

The general discussion chapter (Chapter 7) considers the methodology and experimental limitations. The outcomes of the research presented in this thesis are drawn together, and the implications of key findings are discussed.

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Chapter 2

Literature Review

Introduction: Background on New Zealand's pork industry

Pig production in New Zealand began as an adjunct to the dairy industry. During a time when milk was separated and dairy farmers were paid for milkfat (i.e. cream) only, pigs were fed surplus skim milk and by-products (Gregory and Devine, 1999). The rapid expansion of the dairy industry between 1900 and 1930 saw a concurrent increase in pig production, with numbers peaking at this time. Initially, the pig population was concentrated in the main dairying regions. Once whole milk collection was introduced, there was a sharp reduction in the feeding of separated milk and by-products to pigs in the late 1960s and early 1970s (Gregory and Devine, 1999). Pigs were no longer fed dairy by-products, dairy farmers stopped keeping pigs and pig farming became a separate and more specialised industry. The pig population became more widely distributed away from the dairy farming regions and today the majority of pig meat is produced in areas best suited to producing grains, such as the Canterbury region in the South Island.

The New Zealand pork industry is small by international standards. The average size of a commercial herd is 300 sows. Approximately 100 commercial farms produce around 625,000 pigs per year (NZPIB, 2014). This amounts to nearly 60% of the pork that is consumed in New Zealand, with the rest being imported from Canada, USA, Denmark, Finland, Australia and Sweden (NZPIB, 2014). Approximately 40 - 45% of New Zealand pork producers are based outdoors in 'free range' or 'free farmed' operations (Edge et al., 2007). There is also a significant population (estimated at 10,000 – 20,000 pigs) of "backyard" or "para-commercial" farmers with small-scale herds farmed on smallholdings or lifestyle blocks (Welch, 2012).

The use of gestation stalls after mating was banned in December 2015 after a review of the Animal Welfare (Pigs) Code of Welfare in 2010. As gestation stalls are now banned, farrowing crates remain the only form of restrictive confinement used within the pork industry. Concerns for the welfare of sows housed in farrowing crates is mounting, with animal welfare and animal rights groups actively campaigning against their use.

The National Animal Welfare Advisory Committee (NAWAC) is an independent committee responsible for advising the Minister for Primary Industries on any matter relating to the welfare of animals in New Zealand (Anon, 1999). The responsibilities of NAWAC include developing codes of welfare. The use of farrowing crates was addressed in the 2004 review of the pig welfare code, where it was stated that the use of farrowing crates did not fully meet the obligations of the Animal Welfare Act (1999) as normal sow behaviour is constrained (Anon, 2005). A later review of the pig welfare code in 2010 concluded that the farrowing crate conferred the best protection for piglets, and reduced piglet mortality when compared with other systems. Thus, the current Code of Welfare states a sow must not be confined in a farrowing crate for more than five days before farrowing, and must not remain in a farrowing crate longer than four weeks after farrowing (Anon, 2010).

The status of farrowing crates

In developing codes of welfare, NAWAC must take into account good practice, available technology, and scientific knowledge. The practicality and economic impact of any recommendations may also be considered. Previously, an exceptional circumstances provision existed whereby practices that did not fully meet the obligations of the Animal Welfare Act could be recommended. The obligations of the Act are to ensure that the physical, health and behavioural needs of animals are met. Farrowing crates are an example of a practice that fell under the exceptional circumstances provision. As farrowing crates remain the only form of confinement that is permitted within the New Zealand pork industry, logically, crates are the next practice to be evaluated in terms of their continued use. Indeed, NAWAC stated in the 2010 code that they “want to see farrowing systems shift progressively towards those in which the lactating sow and piglets have the benefits conferred by farrowing crates, while giving the sow an increased opportunity to move and express a greater range of behaviours, including nest building” (Anon, 2010). It was also stated that there was no single alternative farrowing system that met all of the welfare requirements and had commercially acceptable levels of performance. Thus at that time, “no alternative indoor farrowing systems that provide the lactating sow and her piglets with greater benefits than those conferred by farrowing crates have yet reached a stage that NAWAC could, with confidence, require the New Zealand industry to adopt them” (Anon, 2010).

In line with NAWAC’s opinion regarding the future of farrowing crates in New Zealand; no country has completely banned farrowing crates. Switzerland, Norway, and Sweden no longer allow the use of farrowing crates for the entirety of parturition and lactation. That is to say, all of these countries permit short-term confinement in crates under particular circumstances. A revision of the Swiss Animal Protection Ordinance in 1997 first introduced the requirement for loose housing of farrowing and lactating sows, allowing their pork industry a 10-year transitional period out of farrowing crates. The current version of the Swiss Animal Welfare Ordinance states: “Farrowing pens shall be designed in such a way that the sow can turn freely. During the parturition phase, the sow may be restrained in isolated cases, in cases of malice towards the piglets, or in the event of limb problems” (Anon, 2008).

In Norway, there is a ‘general’ ban on the fixation of sows in crates, but the use of crates is permitted for “very restless sows” at the time of farrowing and for a maximum of 7 days following. A survey of 60 Norwegian pig producers revealed that “some or a few” admitted to systematically confining sows in crates during farrowing (Skarstad and Borgen, 2007). It is worth noting that the average herd size in Norway was approximately 37 breeding sows (with approximately 1,600 breeding farms) as recorded in 2009, thus a farrowing crate restriction would not be difficult to manage on such small herds.

In 2007, new regulations for farrowing sows were introduced in Sweden (as per the Swedish regulations DFS 2007:2 L100, Chapter 3): “A nursing sow’s freedom of movement may be confined during the first days after farrowing by the use of a gate or similar construction if she shows aggressive or abnormal behaviour, or behaviour which forms a threat to injure her piglets. A gate or corresponding equipment may also be used during management procedures if the behaviour of the sow is a threat to injury of the manager or during handling of the sow for care and treatment” (DFS, 2007).

The reluctance to completely ban farrowing crates tells us that loose housing options for sows during parturition and lactation need further development. Unacceptable levels of piglet mortality are still a significant barrier to the acceptance of non-crated farrowing systems, and it is crucial that the net welfare of the sow and the piglets are considered in seeking a commercially viable, indoor alternative to farrowing crates.

Observations of sows in natural and semi-natural environments

The European wild boar (*Sus scrofa*) has been the subject of studies that have described their reproduction and behaviour in a 'natural' situation (Baber and Coblentz, 1986; Algers and Jensen, 1990; Mayer et al., 2002; Náhlik and Sandor, 2003; Fernández-Llario, 2004; Andersson et al., 2011a,b; Fonesca et al., 2011). It is of interest to researchers to compare their behaviour to that of domestic commercially bred sows in order to determine the deviation in behaviour of the latter from their wild conspecifics. The issue of accommodating an animal's natural behaviour is often raised in the context of achieving positive welfare outcomes. The assumption is that animals living in a wild or natural state are all in good condition and experience good welfare (Volpato et al., 2009). The implication is that animals which can perform natural behaviour are therefore in a good state of welfare, which may not be the case. Furthermore, 'natural' behaviour of domesticated livestock is the result of their adaptation to an agricultural environment, including regular interactions with humans (Segerdahl, 2007). Thus natural behaviours of wild boar may not be considered natural for domesticated pigs. Nevertheless, behaviour remains a valuable indicator that contributes to an integrated assessment of welfare status.

Nest building behaviour

Farrowing crates limit the sow's ability to perform the pre-farrowing sequence of nest building behaviour (Wischner et al. 2009). Hence, the benefits accrued by piglets in a farrowing crate are offset by significantly restricted mobility and behavioural expression in sows. Most farrowing systems used on commercial farms do not allow sows to seek and achieve isolation prior to farrowing. Behavioural observations of sows in semi-natural environments have shown that in late gestation, sows become intolerant of other group members. Sows may become aggressive towards one another at this time as they seek isolation (Stolba and Wood-Gush, 1984; 1989). Sows in wild or semi-natural environments isolate themselves from their group 1-3 days before they are due to farrow in order to select a suitable nest site.

Nest building behaviour is a strongly motivated activity which occurs in several phases (Grundlach, 1968; Frädrich, 1974). One study observed that wild sows established their nests in places with four characteristics: 1) abundant vegetation cover; 2) a nearby water source; 3) minimum distance of separation with another nest; 4) appropriate temperature (Fernández-Llario, 2004). Once the location of the nest has been chosen, the sow digs a hollow in the ground with her snout. She then collects material including grass, leaves, small branches and twigs to arrange within the nest (D'Eath and Turner, 2009). This material creates an outer edge of the nest hollow that will form its final shape and size. The sow arranges this material by rooting and pawing with the forelegs, turning around within the area as she does so. The nest may then be covered with longer branches, grass and leaves to camouflage and insulate the central lying area (Frädrich, 1974). As the sow prepares to farrow, she will enter the nest and rearrange the bedding material in the central area. Following this period of activity, the sow will lie inactive on one side for a few hours prior to delivery of the piglets (D'Eath and Turner, 2009). Few differences exist between wild sows and domestic free-ranging sows that farrow outdoors with regard to nest building activity (Haskell and Hutson, 1996). However, the final stages of camouflaging the nest are usually unnecessary in domestic outdoor sows, as these sows are provided with farrowing huts that offer cover and isolation from others.

Indoor farrowing facilities do not enable the sow to select a nest site pre-farrowing. Sows in pens covered the equivalent of 350 to 500m per day during the pre-farrowing phase that corresponds to nest-site selection (Haskell and Hutson, 1996). This suggests that when sows have more space than would be provided in a crate, a wider range of strongly motivated behaviour may be displayed prior to parturition. There is evidence that intensively housed sows are still motivated to build nests despite the lack of space and/or materials to do so (Wischner et al., 2009). This provides strong evidence that nest building behaviour is biologically significant (Baxter et al., 2011). Close confinement and/or non-bedded systems considerably limit the sow's ability to build a nest. The implications of this restriction are that the sow may experience stress, leading to altered or misdirected behavioural displays such as directing rooting and pawing activities at pen fittings and flooring (Hartsock and Barczewski, 1997). Pre-parturient crated sows with no bedding changed posture more frequently, spent more time sitting, and exhibited greater Hypothalamic-Pituitary-Adrenal (HPA) axis activity than sows in pens with straw bedding (Jarvis et al., 2001). Whilst the onset of nest building is hormonally-controlled, the performance and completion of nest building behaviour is thought to be regulated by a combination of hormonal and environmental feedback

(Arey et al., 1991; Jensen, 1993; Damm et al., 2000). This raises the question as to whether the sow ‘needs’ to build a nest so as to switch off this behavioural sequence in order to prepare for the onset of parturition (Johnson and Marchant-Forde, 2009). The first phase of this sequence is the onset of nest building, which is triggered by endogenous stimuli beginning with a rise in prolactin (Widowski et al., 1990; Castrén et al., 1993) and a concurrent decrease in progesterone and increase in prostaglandin (Burne et al., 2001; Algers and Uvnäs-Moberg, 2007). The completion of nest building is thought to be strongly correlated to the significant rise in oxytocin levels ~4 hours prior to expulsion of the first piglet (Castrén et al., 1993). The second phase is dependent upon external stimuli from the nest itself. That is, the construction of a satisfactory nest serves as feedback to signal the completion of nest building. The purpose of a nest is largely redundant in an indoor environment, where isolation, separation, warmth and shelter are provided for the sow and her litter. As such, it may be expected that nest building behaviour would not be performed in indoor sows; however domestication has not significantly altered the expression of this behaviour. Commercially farmed sows in an outdoor environment still show behavioural patterns that are similar to those of wild boar during nesting, and despite four previous farrowings in confinement, indoor sows built nests identical to that of wild boars (Gustaffson et al., 1999).

Parturition to weaning

Farrowing often begins a few hours after the end of nest building. The sow will be behaviourally passive at this time, and postural changes are rarely performed whilst the sow gives birth. An exception to this has been observed on occasion, (in sows kept in a semi-natural environment) where a sow may stand and investigate the first few piglets that are born (D'Eath and Turner, 2009). Sows do not engage in individual maternal investment of piglets postnatally (Kilgour, 1985). Piglets are covered in transparent fetal membranes at birth, which dry relatively quickly and slough off. Those that are born enclosed within fetal membranes must free themselves. Sows do not lick their offspring to help release them from membranes and aid rapid drying after birth (Fraser, 1984; D'Eath and Turner, 2009). The umbilical cord is torn when the piglet becomes active in an effort to locate the udder. This passivity of the sow is a likely consequence of giving birth to a large number of precocial young (Johnson and Marchant-Forde, 2009). If sows attended to each individual piglet as they were born, the risk of accidental crushing would be much greater and the duration of farrowing would be extended significantly, to the detriment of piglets yet to be born.

Sows in wild and semi-natural environments remain inactive for the first 48 hours after farrowing has finished, spending 90% of their time lying in their nest (Jensen, 1986). This is once again likely to reduce piglet crushing and allow the piglets to develop teat order and teat fidelity. Piglets stay close to one another and to the sow to conserve body heat through huddling. They generally do not leave the nest in the first few days. The sow forages very little at this time, remaining close to the nest site (Johnson et al., 2001).

In the first 1-2 weeks, the sow may leave the piglets unattended for short periods to eliminate away from the nest and forage for food. Observations of wild sows suggest there is a limit to the maximum area a sow will move away from the nest, estimated at approximately 20 hectares (Mauget, 1981). Farrowing is often synchronised within a group of sows, and a sow and her piglets will stay away from other sows for at least the first 7 days post-farrowing (Jensen, 1988). This prevents competition with non-littermates for milk (Fraser et al., 1995), whilst simultaneously reinforcing recognition between the sow and her offspring. Recognition is likely initiated by the piglets through vocalisations and nose-to-nose contact with the sow (Newberry and Wood-Gush, 1985; Petersen et al., 1989, Petersen et al., 1990). Often the sow will re-join the group for morning feeding a week after parturition. The piglets will continue to use the nest for a further two to three days before abandoning it (Johnson and Marchant-Forde, 2009). At two weeks old, the litter accompanies the sow when she is foraging, bringing them into regular contact with other members of the group. This changes the social interactions of the piglets from within their litter towards similarly aged non-littermates (Petersen et al., 1989).

Weaning is also a gradual event. At first, the frequency of suckling declines from the first week postpartum. The number of suckling events terminated by the sow, and the frequency of nursing events that do not result in milk let-down both increase (Horrell, 1997). Ingestion of significant quantities of solid food begins at around 4-5 weeks of age (Petersen et al., 1989; Jensen, 1995). The number of piglets that are absent during a suckling event also gradually increases with age. In wild pigs, weaning age can vary within a litter (Jensen, 1995). The completion of weaning has been estimated by several authors, varying from 14-17 weeks (Jensen, 1986), 15-19 weeks (Jensen and Recén, 1989), and 8-14 weeks (Newberry and Wood-Gush, 1985).

Piglet mortality in wild boar

The litter size (total born) of wild boar is large in relation to their body size. Litter sizes of captive wild boar vary with the size and age of the sow in addition to feed availability (Mauget, 1981). The variation in total born has been reported as ranging between 1 and 7, with a mean of 3 piglets per litter. Farmed wild boar have produced litters with a mean of 5.4 ± 1.5 piglets born (Harris et al., 2001). A relatively large litter size is associated with high pre-weaning piglet mortality. In fact, the evolutionary strategy of the pig is to produce a large number of offspring, to compensate for the probability of piglets dying. This allows for flexibility in response to environmental conditions that may or may not provide plentiful resources and adequate lactation performance as a result (Rutherford et al., 2011). Hence, mortality of the weakest piglets is to be expected, and those that cannot be reared due to limited resources will die in the early postnatal period (Edwards, 2002).

Annual fluctuations in offspring survival have been observed in feral populations of swine due to climatic conditions and feed availability (Fernández – Llario and Carranza, 2000; Náhlik and Sándor, 2003). An investigation of the reproductive performance of wild boar females estimated postnatal mortality by calculating average litter size, and subtracting this from the average number of extended visible teats (Fonesca et al., 2011). Extended visible teats were used as an indication of the number of piglets that each sow was suckling (N = 39 sows with a mean of 3.9 ± 1.3 SD piglets). In the two months following parturition it was found that postnatal piglet mortality averaged 6.3% (5.1% in gilts and 10.2% in older females) (Fonesca et al., 2011). However one factor to consider, given that sows often farrow synchronously in the wild, is that piglets may cross-suckle from multiple sows. Therefore, the same piglet/s may have been counted more than once based on visible evidence that udder segments of different sows showed evidence of milk production and suckling activity. Therefore postnatal mortality in the first two months of life may have been underestimated in this study. This is likely considering other reports of much higher piglet mortality in wild populations of swine. The mortality of piglets in the wild can reach 17% during their first few weeks of life (Martys, 1982) and it has been suggested that the natural postnatal mortality is in the range of 5% to 25% (Briedermann, 1971). One study of a free-ranging population of wild boar found piglet mortality reached 55% of live born offspring in one year and 61% in the subsequent year (Náhlik and Sándor, 2003).

A study based in a 10 ha wild boar habitat in Sweden was the first to document piglet mortality caused by sows killing the offspring of other sows. Non-maternal infanticide was recorded in 14 out of 22 wild boar litters observed, and in all but one of the 14 litters, every piglet was killed (Andersson et al., 2011b). A paired comparison of perpetrators versus victimised sows showed that the perpetrators were always older than the victim sow. Perpetrators killed piglets from related females (e.g. sisters and daughters) but never attacked their mother's litter (Andersson et al., 2011b). The majority of attacks occurred whilst sows were still farrowing.

The same study surveyed owners and keepers of wild boar enclosures in Sweden and Finland. Based on 62 responses the most common cause of piglet mortality was non-maternal infanticide (36%) followed by accidental crushing by the sow (27%), predation by other species (18%) and maternal infanticide (15%). Total pre-weaning mortality was estimated at 29.1% (Andersson et al., 2011b). Infanticidal behaviour may be part of the normal repertoire of behaviour in wild boars, as it conveys some benefits to the perpetrator. Infanticidal sows may exploit non-offspring as a food resource, which is a likely conclusion given that all piglets killed were also eaten. Killing the offspring of another sow has the advantage to the perpetrator of reducing competition for resources (Ebensperger, 1998). In a fixed area such as an enclosed habitat, or in poor environmental conditions, resources may be perceived as limited. These findings have provided some significant insight into the welfare challenges experienced by populations of wild pigs.

Compromises between sows and piglets: 'The triangle of needs'

Modern sows are highly prolific, owing to generations of extensive genetic selection to increase the total number of piglets born per litter. In Denmark, litter size (total born) increased by 33% between 1996 and 2009, but the number weaned per litter increased by 23% in the same period. In the same period the number of stillborn piglets doubled from 0.9 to 1.9 piglets per litter (Rutherford et al., 2011). One consequence of large litter size is greater within-litter birth weight variation and a greater proportion of physiologically immature piglets within a litter (Tuchscherer et al., 2000). Within-litter variation at birth is the result of limited availability of nutrients to each fetus, which is, to an extent controlled by uterine blood flow, fetal position in the uterus, and litter size (Edwards, 2002). Larger litters result in longer farrowing duration, and a longer interval between the birth of successive piglets, as prolonged farrowing causes maternal exhaustion (Lay Jr. et al., 2002). Piglets from larger litters take longer to achieve their first suckle given that there is more competition at the udder. Low viability piglets have a lower rectal temperature one hour after birth due to an impaired ability to maintain thermoregulation (Tuchscherer et al., 2000).

The large increase in the reproductive performance of sows has been managed through more supervision and intervention of the farrowing process, and specific management practices such as the use of farrowing crates. However, the latter has resulted in compromises to sow welfare, which are discussed in a later section of this review. The solution to this may lie in the development of farrowing systems that address the conflicts of interest between the sow, the piglets, and the farmer. The design of such a system should consider the biological needs of the sow and her litter (Baxter et al., 2011). Hence a confinement-free alternative to the farrowing crate would need to meet all of the benefits (including the economic and animal-based aspects) of a conventional crate whilst achieving an overall improvement in both sow and piglet welfare. The emphasis here is on *both* the sow and the piglets; as it is important not to merely shift the balance towards improving sow wellbeing to the detriment of piglet welfare.

Balancing the needs of sows and piglets is a challenging task, as a farrowing system must accommodate two different ‘types’ of animals with specific needs. Every farrowing system design therefore carries a degree of welfare compromise. The sow is transitioning from one physiological state (gestation) to another (lactation). The piglets must rapidly adapt to their sudden introduction into an unpredictable extra-uterine environment that greatly differs from the previously controlled, buffered intrauterine environment (Nowak et al., 2000). Thus sow and her litter have a very different set of requirements that often contradict one another.

Piglet survival to weaning is one of the most important measurable outcomes of the farrowing and lactation period (Baxter et al., 2011). This key performance indicator is of interest to the piglets, the sow, and the farmer, who together form the 'triangle of needs' (Baxter et al., 2011). The survival of the piglets affects the sow through indicating her reproductive and maternal capability. Thus, a sow that rears a litter with high mortality may be culled on the basis of poor performance. The farmer's requirements align well with that of the piglets' as the farmer needs as many healthy, well grown piglets as possible to survive to weaning, which directly influences farm profitability. It is also important that the safety of stockpersons is considered in the design of a farrowing system. If access to sows and piglets is difficult or poses a risk to their safety, routine husbandry procedures may not be carried out properly, which could compromise animal welfare (FAWC, 2015). However, in any farrowing system, the largest conflict of interests exists between the sow versus the piglets.

One such example of a conflict between the sow and the piglets is their requirement for space. A combination of static and dynamic space is required in the farrowing area. Static space must accommodate a sow lying laterally whilst giving birth and nursing her litter. Dynamic space is required for piglets to be born safely, allowing room for newborns to stand, locate the udder and suckle (Baxter et al., 2011). 'Adequate space' from a sow's perspective suggests that she needs to be able to turn around. In a natural or semi-natural environment, a sow will stand up and turn around to inspect a newly-born piglet, before lying down again to give birth to more offspring (Gundlach, 1968; Jensen, 1986). This interaction with the piglets may facilitate mother-young bonding, through olfactory and auditory cues in pigs (Illmann et al., 2002; Kittawornrat and Zimmerman, 2011). In a commercial setting, this behaviour is probably redundant as the sow and her piglets are separated from others, and piglets are removed from the sow at weaning (Baxter et al., 2011). Reciprocal communication between sows and piglets may, however be instrumental in promoting positive maternal behaviour towards piglets (Andersen et al., 2005).

As lactation progresses, sows prefer to spend more time away from their piglets (Bøe, 1991; 1993; 1994). This mimics the gradual weaning approach, whereby over time sows increase the amount of time between nursing bouts. Sows housed in farrowing pens with a 'piglet-free area' for the sow to retreat to tended to increase the amount of time they spent away from their piglets as lactation progressed (Pajor et al., 2000). In the last two weeks of a 5 week lactation, sows spent 70% of their time in the piglet-free area, which coincides with the timing at which piglets are normally weaned (4 – 5 weeks of age) in a commercial setting. In a farrowing system designed to allow sows to leave their piglets at will, there was significant between-sow variability in the amount of time sows spent with their litter as lactation advanced. Some sows abandoned their litter so early that piglet health and growth was detrimentally affected (Bøe, 1993). The investigation of sow-controlled farrowing systems has indicated that sows prefer to regulate the amount of contact they have with their piglets. Whilst this may reduce stress associated with continuous confinement with the litter, the opportunity to avoid piglets may lead to inadequate care for the young.

Another compromise between sows and piglets relates to their thermal requirements. At birth, piglets are neither equipped with brown adipose tissue to support thermogenesis (Herpin et al., 2002), or adequate subcutaneous adipose tissue reserves. Newborn piglets experience rapid cooling as a consequence of evaporating fetal fluids on the surface of the skin. The regulation of homeothermic balance depends on an ability to produce heat. A sudden 15-20˚C decrease in ambient temperature is experienced at birth, resulting in an inevitable fall in body temperature by approximately 2˚C within the first 20 minutes of life (Herpin et al., 2002). The neonatal pig shivers vigorously from birth, and possesses very little adipose tissue (1-2%) of any type (Mersmann, 1974). In healthy newborn piglets, body temperature rises to a normal value of 39˚C within 48 hours. Conversely, the thermal comfort of sows is achieved in the range of 12°C and 22°C (Black et al., 1993) and temperatures above 22°C increase the risk of heat stress and depressed feed intake, thus affecting milk production and piglet growth.

Sow and piglet welfare and behaviour in farrowing crates and farrowing pens

More than 50 years ago, pig farms became larger, moved indoors and became more intensified. This intensification increased productivity, largely achieved by greater control over the breeding, feeding, and general management of sows (FAWC, 2015). The original design of the farrowing crate has been modernised over time. Today's farrowing crates use durable materials that are more hygienic and easy to clean, with non-slip flooring, adjustable crates to accommodate variable sow size, and technology that controls temperature, ventilation, feeding and even cleaning. Despite this modernisation, the basic concept and function of the farrowing crate remains unchanged, as the objective of the farrowing crate is to reduce piglet mortality and maximise the number of piglets weaned per litter. This is accomplished through restricting the mobility of the sow, limiting her movement to standing, sitting, or lying.

The key issues associated with confinement of sows in crates are the conditions during that confinement, and its duration (FAWC, 2015). Sows are routinely confined in crates 5 days prior to farrowing. A number of studies have described the effects of confinement on the stress response of the sow. Gilts confined to farrowing crates during the pre-parturient phase had higher adrenocorticotropic hormone (ACTH) levels and higher cortisol levels than gilts housed in pens during the same period (Jarvis et al., 2002). Gilts in crates showed greater activation of the pituitary-adrenal axis, thus stress was induced as a result of limited physical movement and thwarted nest building behaviour, which are consequences of a farrowing crate environment (Jarvis et al., 2002). Reports of higher heart rates (Damm et al., 2003), and elevated plasma cortisol (Lawrence et al., 1994; Jarvis et al., 1997, 2001) in crated sows compared to those in loose pens suggest that crated sows experience more stress. Prolonged confinement in crates can have an adverse effect on welfare, as cortisol levels on day 29 of lactation were higher in crated sows than those housed in farrowing pens (Jarvis et al., 2006). However, towards the end of the fourth week of lactation sows in both crates and pens showed signs of an elevated stress response, which was attributed to an inability to avoid their piglets (Cronin et al., 1991). Conversely, saliva cortisol levels were shown to decrease throughout lactation, and there was no difference between saliva cortisol levels of sows with a normal lactation length of 25 days, or nurse sows which had an extended lactation of 31 or 38 days (Amdi et al., 2015).

The farrowing and lactation environment can influence the physiology of the sow, leading to consequences for the farrowing process itself. One example of this is the duration of farrowing, where a shorter duration reduces the risk of piglets being stillborn (Oliviero et al., 2010). The farrowing duration of sows in crates was 93 minutes longer than sows in pens with straw bedding (Oliviero et al., 2008). The interval between the birth of successive piglets was also longer in crated sows compared to sows in pens. A shorter farrowing duration in penned sows may be attributed to an increased comfort level, particularly if bedding material is present.

The maternal ability of sows should be considered alongside developments in non-crated farrowing systems. Selection of sows for temperament based traits may enable safer handling by stockpersons, and will therefore be advantageous in a confinement-free system. A focus on improving maternal behaviour may also complement genetic selection for improved piglet survival. It should be noted that human care of young farm animals may have inadvertently led to relaxed selection for maternal traits (Price, 1984). This is particularly relevant to intensively farmed pigs, and may explain the variability with which domestic sows express some characteristics of maternal behaviour.

The maternal behaviour of sows has been the subject of many studies with the objective of improving piglet survival by identifying traits that could improve maternal care. These traits may include a sow's reactivity to separation from her litter (Herskin et al., 1998; Hellbrügge et al., 2008), and her reaction to piglet distress calls (Thodberg et al., 2002; Hellbrügge et al., 2008; Melišová et al., 2014). Responsiveness to piglets is an indicator of good maternal care (Pedersen et al., 2003) and with the development of reduced-confinement farrowing systems, it is more and more important that sows respond to piglet signals and react carefully (Grandinson, 2005). Other behavioural traits of interest include whether sows carefully perform a sequence of pre-lying behaviour to warn piglets before lying down, as opposed to "flopping straight down"

(Wechsler and Hegglin, 1997). However, within one type of farrowing environment there is a large variation in piglet mortality among sows (Wechsler and Hegglin, 1997; Andersen et al., 2005), which may be explained by individual differences in maternal ability as opposed to the design of the system. Maternal behaviour is more important in non-crated farrowing systems however, due to its direct influence on piglet survival.

Less is known about what may influence piglet behaviour. Certainly, interactions between the sow and her piglets may affect their behaviour. For example, piglets move closer to the sow when she vocalises towards and sniffs at them (Melišová et al., 2011). Their behaviour can be influenced by the farrowing environment. Piglets born and reared in enriched loose farrowing pens spent more time interacting with a novel object than with a familiar object compared to piglets born and reared in farrowing crates (Martin et al., 2015). Piglets in pens also interacted with sows sooner after birth than piglets in crates, and performed more play behaviours pre-weaning. However, there were no effects of the pre-weaning environment on post-weaning behaviour, thus the farrowing system's influence upon piglet play behaviour was short-lived. In a more complex pen-based farrowing system, piglets also have more space which may provide greater opportunities for active play behaviour and exploratory behaviour compared to those reared in farrowing crates. Space availability also influences piglet mortality, which was significantly higher with the use of a large farrowing nest (18.1% mortality rate in a $4.0m^2$ nest) compared to a small nest (10.9% mortality rate in a $3.3m^2$ nest) (Baxter et al., 2015). In a larger area, sows are more active thus piglets may wander away from the sow in order to avoid her when they recognise cues that she may be about to change posture. In turn, this might place piglets further from their heat source which predisposes them to hypothermia, weakness, and starvation.

Performance of sows and piglets in farrowing crates and farrowing pens

One limitation to comparing performance data across several studies is that the use of the word ‘pen’ does not convey the design features and functions that can have a significant influence on performance outcomes, including piglet mortality (which is comprehensively discussed in a later section of this review). For example, crushing mortality was reported in a study comparing three farrowing systems: farrowing crates, farrowing pens, and freedom farrowing pens (Gu et al., 2011). The distinction made between the two types of pen was that the freedom farrowing pens were fitted with anti-crushing rails to the left and right of the sow area, as well as within what was described as the non-lying area. The farrowing pens had the same dimensions as the freedom farrowing pens, without any anti-crushing rails. Crushing mortality was reported as 10.8% in farrowing crates, 9.3% in freedom farrowing pens, and 25.5% in farrowing pens (Gu et al., 2011). The addition of piglet protection rails in the freedom farrowing pens clearly made a difference in reducing piglet mortality relative to that which was achieved in the farrowing pens. Referring to these systems simply as ‘pens’ would raise questions as to why crushing mortality was significantly higher in one pen compared to the other.

That being said, there needs to be a balance between describing pen – based farrowing systems in an uncomplicated manner whilst being clear about what sets them apart. Through examining the literature it would appear that there are three categories that describe the majority of farrowing pen designs. These categories could be described as follows:

1) Simple loose pen: These are basic in design and construction, usually at or just above the minimum size required for a sow to turn around comfortably (~5m^2). These pens are functional and easy to clean, however there is usually no separation of the nest area (where the sow rests) and the dunging area. The majority of the floor is usually fully slatted, if not the entire floor surface. Piglet protection may be present but is often rudimentary (i.e. rails around the internal perimeter) with a basic piglet creep area.

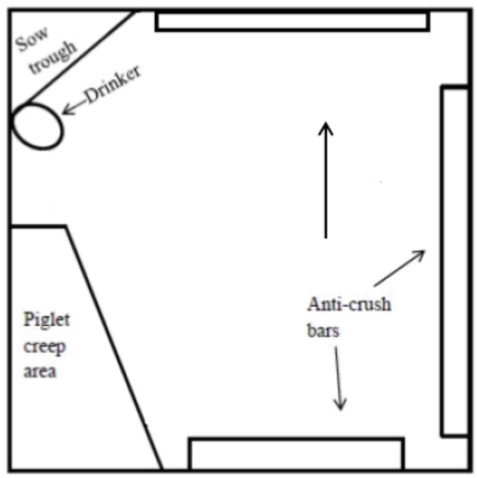

Figure 2.1. Simple loose pen

2) Designed loose pen: Generally larger than the aforementioned simple pen, with a nest area for the sow that usually has a solid floor to accommodate bedding and promote nesting behaviour. There may be features such as: sloped panels on the walls to assist sows to lie down easily whilst protecting piglets from being trapped between the sow and a wall; straw racks to provide bedding material on demand; and 'get-away' areas where sows can control the amount of time they spend with piglets. Designed pens have a separate dunging area which is usually the only slatted section of the floor. The design is focused on enrichment, sow comfort, meeting the behavioural needs of sows pre-farrowing, and the piglets' requirements for a comfortable and separate thermally controlled creep area.

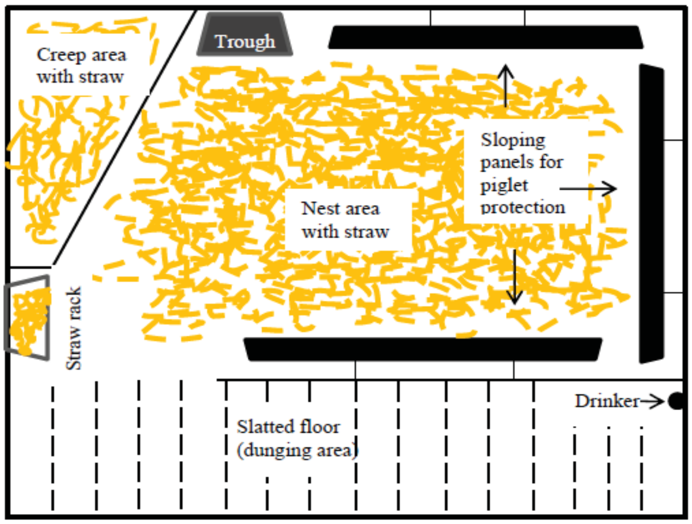

Figure 2.2. Designed loose pen

3) Two – stage pen: These pens may be simple or designed, but the key difference is that they have an inbuilt farrowing crate. Two – stage pens balance the needs of sows and piglets through restricting sow mobility when piglets are most at risk of mortality (usually 3 – 7 days post-farrowing). Sows still have freedom of movement for the majority of lactation after the crate has been disassembled.

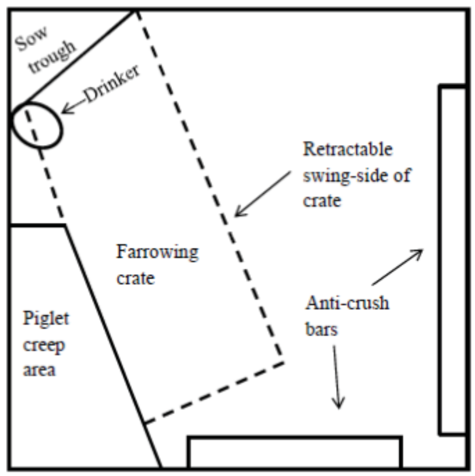

Figure 2.3. Two – stage pen

The overall welfare outcome of a farrowing system is influenced by many on-farm factors. These include the design of the farrowing accommodation, herd health status, genetics, the maternal ability of sows, nutrition, gestation management and stockmanship. Many of these factors will also affect farm productivity, regardless of the farrowing system. One such indicator of the efficacy of a farrowing system (and to an extent, how well that system is managed) is the pre-weaning piglet mortality rate. This indicator is also used to gauge piglet welfare when comparing different systems. It is evident when comparing these studies that piglet mortality differs between farrowing system types (crate vs. pen, Table 2.1). However there are also differences in mortality within the same system. Studies comparing farrowing systems across multiple farms may involve different genotypes, varying numbers and skill level of staff, and have different approaches to management, which could all influence performance outcomes within a similar farrowing system (Table 2.1).

Table 2.1. Summary of piglet mortality in farrowing crates and farrowing pens

Publication	Crate mortality (%)	N		Pen mortality (%)	N	
		Litters	Herds		Litters	Herds
Pedersen and Ingwersen, 1981[1]	10.2	1085	-	10.5	697	-
Gustafsson, 1983[1]	18.7	15607	-	18.7	56900	-
Cronin and Smith, 1992[2]	10.5	32	1	16.5	32	1
Bäckstrøm et al., 1994[3]	18.7	765	-	16.9	3219	-
Blackshaw et al., 1994[3]	14.0	8	1	32.0	8	1
Arey and Sancha, 1996[1]	25.2	24	1	28.5	24	1
Cronin et al., 2000[1]	17.5	80	1	15.5	66	1
Marchant et al., 2000[2]	15.2	66	1	24.8	66	1
Jarvis et al., 2005[2]	5.6	71	1	12.2	51	1
Weber et al., 2007[1]	12.1	44837	482	12.1	8824	173
Edwards et al., 2010[3]	12.8	152	1	14.9	152	1
KilBride et al., 2012[1]	11.7	1000	49	10.9	1000	15
Hales et al., 2014[1]	11.8	633	3	13.7	735	3
Melišová et al., 2014[1]	11.3	18	1	11.9	20	1
Morrison and Baxter, 2013[1]	13.5	143	1	14.9	145	1

[1]Differences between crate and pen mortality were not significant
[2]Differences between crate and pen mortality were significant ($P < 0.05$)
[3]Differences between crate and pen mortality were not specified

The most common cause of piglet death pre-weaning is accidental crushing (Svendsen et al., 1986; Marchant et al., 2000; Andersen et al., 2005). Crushing-related deaths have been reported as higher in pens than in crates (0.62 piglets per litter in pens; 0.52 piglets per litter in crates, Weber et al., 2007). Crushing mortality was also higher in gilt litters that were farrowed in pens (1.4 piglets per litter) compared to crates (0.6 piglets per litter) (Jarvis et al., 2005), and a greater rate of piglet crushing was recorded in penned sows (45%) than in crated sows (20%) (Cronin et al., 2000). It is generally agreed that there is a greater risk of piglet crushing, and hence higher piglet mortality, in farrowing systems with reduced or no confinement in crates.

The design of pen-based alternatives to crates can influence whether or not acceptable levels of performance are achieved. The management of these systems is perhaps a more important factor in their success. Researchers have been developing non-crate farrowing systems for the last 30 years (Morrison et al., 2013). Going back to the ‘triangle of needs’ between the sows, the piglets and the farmer; at this stage it is unlikely that a new ‘invention’ could meet all of the requirements of each of these stakeholders. Indeed, farrowing crates have never met the needs of all three simultaneously. Refinement of existing alternatives to crates may further improve the performance, welfare outcomes and management of these systems, but there is still a long way to go before universal commercial adoption of non-crated farrowing systems occurs. One reason for this is the lack of large scale, commercial experimental data comparing performance between pen-based farrowing systems and farrowing crates. Furthermore, there are few reports of a wider range of piglet performance parameters across different farrowing systems. Piglet birth weight, daily growth rate, and weaning weight did not differ between farrowing crates and PigSAFE farrowing pens (Morrison and Baxter, 2013) despite sows in PigSAFE pens having a higher feed intake (7.6 kg/day) than sows in farrowing crates (7.3 kg/day) during the same study. Sows in PigSAFE pens also lost more live weight during lactation (27 kg) compared to those in farrowing crates (21 kg) (Morrison and Baxter, 2013). Thus, further development was recommended in order to increase the commercial viability of this particular farrowing system.

Even the systems designed as alternatives to farrowing crates have raised concerns for the welfare of sows. Some of these concerns originate from problems with design. The optimal space required by the average sow varies through different stages of the farrowing and lactation period, thus in reality one design is not likely to meet all of the needs of the sow at each of these stages. True expression of nest building is still prevented in pens through a lack of adequate space for sows to meet their needs for increased locomotion (Edwards, 2008). Solid floors are a better option if bedding is provided, as this reduces the loss of material through slats. However solid flooring can create hygiene issues with the accumulation of waste and soiled bedding. For this reason, slatted flooring is preferred for the farrowing environment, which then precludes the use of bedding material (Edwards, 2008) and likely reduces sow comfort.

Over the last three decades, many pen-based alternatives to farrowing crates have been developed and investigated in terms of performance outcomes and welfare implications. These studies highlight significant variability regarding performance and piglet mortality across a multitude of designs. Evidence of consistently acceptable results under commercial settings is needed in order to further our understanding of the level of performance that is achievable on-farm. Furthermore, the farrowing environment has an impact on some characteristics of maternal behaviour, and subsequently, the survival of piglets. However, less is known about the influence that alternative farrowing systems may have upon modifying sow behaviour to the extent that offspring reared in these systems have a different experience of maternal care than those reared in crates.

Behavioural plasticity and the transmission of maternal behaviour to future generations

Prenatal interactions between the dam and the fetus/ fetuses influence their growth and development. These interactions are variable, and result in long-term consequences for the physiology and neurobiology of the offspring. Prenatal experimental manipulations of stress have demonstrated effects on maternal behaviour, physiology and the neuroendocrine system (Meek et al., 2001; Maccari et al., 2003; Brunton, 2013; Rutherford et al., 2014). The effects of such manipulations upon the pregnant dam can correspondingly "programme" the fetus, altering the fetal phenotype in response to environmental cues.

One such example of these long lasting effects has been shown in daughters born to sows that were mixed with unfamiliar sows during pregnancy (Jarvis et al., 2006). Mixing sows with unfamiliar individuals causes aggressive behaviour and stress as the social hierarchy of the group is disrupted (D'Eath and Lawrence, 2004). Daughters of stressed sows made more postural changes than the daughters of control sows during the pre-parturient phase, an indication of greater restlessness. These gilts were more responsive to approaches made by their piglets and they bit at their piglets more often than control gilts (Jarvis et al., 2006). Greater restlessness and heightened reactivity to piglets has been associated with abnormal maternal behaviour such as savaging (Ahlström et al., 2002; Chen et al., 2008). The only physical attacks of piglets were performed by the daughters of prenatally stressed sows. Through programming the HPA axis of the female offspring born to prenatally stressed sows, long term effects on maternal behaviour were apparent. Altered maternal behaviour in the programmed offspring could lead to transmission of the programmed phenotype to future generations.

The interactions between mammalian mothers and their offspring are also influenced by the environment experienced in the early perinatal stage of development. Variation in the quality and/or quantity of maternal care can have consequences for the development of neuroendocrine processes that dictate the subsequent reproductive and maternal behaviour of female offspring (Champagne, 2011). The basic mechanisms of maternal behaviour can be altered by the nature of reciprocal interactions between the dam and her neonatal offspring. A dam's response to the environment, and the level of care expressed towards her offspring can determine whether there are changes to their physiology, neurology and/or behaviour. There is evidence that in the case of maternal care, behavioural transmission of postpartum behaviour from dam to daughters does occur (Champagne, 2008). Furthermore, there may be transmission of these phenotypic neurodevelopmental changes to subsequent generations through altered maternal behaviour in adult offspring. The implication of this is that epigenetic mechanisms are responsible for mediating this transmission (Champagne, 2008) which can potentially be expressed in the original dam followed by her female offspring as well as in the next generation.

Young animals must be adequately cared for in order to develop physiologically immunologically and socially. Species-specific mother-young interactions promote this development and increase the likelihood that the offspring will survive. Therefore in future, those individuals will mate and successfully rear their own offspring (Fleming et al., 1999). In more recent years, these reciprocal behaviours have been investigated in depth. The previous assumption that mother-young interactions are stereotyped and relatively fixed between generations has been replaced with the notion that they may in fact be plastic. Hence, the experience at parturition and during the early postnatal period (of both the mother and her offspring) may markedly influence future behaviour of both.

Several studies have implied that a strong relationship exists between the level of care expressed by the dam, and the maternal behaviour of her female offspring (Fleming et al., 1999; Fleming et al., 2002; Weaver et al., 2004). A high level of maternal care is associated with reduced HPA axis responses to stress, and reduced anxiety-like behaviour in later life (Brunton, 2013). Data from studies that have cross-fostered offspring amongst rodents suggests that the mode of this inheritance of maternal characteristics is not genetic; but rather it is transmitted behaviourally. The adaptive value of behavioural plasticity may be that it permits a degree of flexibility that allows offspring to be nurtured in widely varying and unpredictable environments. Hence the significance of plasticity in the context of maternal neurobiology and behaviour is the potential for improving reproductive fitness (Groothuis and Taborsky, 2015). This may arise through modifications in the care of subsequent offspring based on previous mother-young interactions. The effect of parity has been clearly demonstrated; where the offspring of an experienced dam often have an advantage over the young of first time mothers (Fleming, 2008). Individuals born to higher parity dams are more likely to be cared for in adverse conditions, receiving better nutrition, and more attention from their more capable mothers (Fleming, 2008).

It follows that the quality of these interactions are influenced by early environmental experiences. Rat pups which received more interaction from their mothers in the form of being licked and groomed, expressed higher levels of this behaviour towards their own offspring than those that received low maternal interaction (Francis et al., 1999a, b). When offspring from low-licking mothers were cross-fostered to high-licking mothers, they showed high propensity of licking behaviour when they matured and vice versa (Francis et al., 1999a, b). Therefore, the neonate became experienced through exposure to the actions of the dam. Data from cross-fostering studies suggests that the transmission of maternal behaviour can be modulated through non-genetic means, namely through a neurobiological change in offspring as a result of the quality of mother-young interactions.

Natural variations in maternal care can influence the stress reactivity of offspring. The amount of tactile stimulation received by rat pups has been shown to alter their gene expression, physiology, and behaviour (Liu et al., 1997; Caldji et al., 1998; Francis et al., 1999a, b). Adult offspring of high-licking dams are behaviourally less fearful and exhibit a more moderate HPA response to stress compared to offspring of low-licking dams (Liu et al, 1997). The level of maternal interaction experienced in rat pups has also been shown to affect their behavioural response to novelty (Caldji et al, 1998). Adult offspring born to dams that engaged in high maternal care in the form of arched-back nursing (ABN) and licking and grooming (LG) showed more exploratory behaviour in an open field test (Caldji et al., 1998). These offspring also showed a significantly shorter latency to begin eating food placed in a novel environment compared to offspring of low LG and ABN dams. The level of maternal care influenced the development of neural systems that are associated with the expression of fear (Caldji et al., 1998).

It has been demonstrated in rats (Francis et al., 1999a,b; Champagne et al., 2003), monkeys (Maestripieri 2005), pigs (Oostindjer et al., 2011) dogs (Slabbert and Rasa 1997), prairie vole (Perkeybile et al., 2015) and many other animals, that their young can learn how to behave through observing as opposed to imitating their mothers. A behavioural pattern is described as ‘learned’ when the effect of the observation remains for an extended period after the initial observational experience (Klopfer, 1961). Learned behaviours occur during habituation to an environment, such as an intensive housing facility. This form of learning is beneficial to an animal's welfare, as their behavioural repertoire is adjusted to suit the system which reduces fear and anxiety (Scipioni et al., 2009). Successful adaptation of an animal to a production system would therefore make that system more acceptable in terms of the animal's welfare, through reducing the mismatch between an animal and its environment (Knap, 2012). However, the domestication of pigs has occurred at a much slower rate compared to the relatively short period of development of current intensive housing facilities. Compromises to animal welfare will therefore still exist where adaptation has not kept up with intensification.

Conclusion

There is a compromise between the needs of the sow and her litter in all types of farrowing systems. Alternatives to farrowing crates have been developed over the last 30 years, and whilst Switzerland, Sweden and Norway have placed significant restrictions upon the use of farrowing crates; there is yet to be an unequivocal ban of farrowing crates anywhere. It is generally accepted that piglet mortality is higher in non-crated farrowing systems, which is the main reason as to why these options have not been universally adopted at a commercial level.

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Chapter 3

Sow and piglet productivity and sow reproductive performance in farrowing pens with temporary crating or farrowing crates on a commercial New Zealand pig farm

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Abstract

The use of a pen during lactation provides sows with more space so they can turn around freely. They are an alternative to the physically and behaviourally more restrictive farrowing crates. Previous studies have compared data from multiple pork production units using different farrowing accommodation types. This study was carried out on one commercial pig farm using two lactation systems. The objective was to examine the effect that the accommodation (pens with temporary crating until 4 days postpartum, or farrowing crates for the duration of lactation) had on the productivity of sows and piglets. Performance data were obtained from 394 sows (4706 live born piglets) in combination pens and 338 sows (3987 live born piglets) in crates over 14 farrowing batches. Pre-weaning piglet mortality (PWM) was significantly higher in the pen system (10.23%) than in the crate system (6.10%) (P<0.0001). Penned sows were released from the temporary crate on the fourth day of lactation. A greater proportion of piglets died in the combination pens (38.8%) than in the crates (30.43%) during the period extending from the fourth day of lactation until weaning (P<0.0001). Total pigs weaned per litter differed (P = 0.0024) between pen (10.54 ± 0.052) and crate systems (10.76 ± 0.065). The accommodation in which a sow farrowed and lactated had no significant effect on subsequent reproductive performance.

Introduction

In New Zealand, about 60% of all pork production units use farrowing crates (Welch, 2014). The remainder produce pork in extensive, outdoor systems. The Animal Welfare (Pigs) Code of Welfare (2010) Minimum Standard No. 10 limits the use of farrowing crates to a period that extends from 5 days before parturition until weaning occurs at a maximum of four weeks after farrowing (Anon, 2010). Farrowing crates were developed to improve production efficiency and minimise piglet mortality. Farrowing crates facilitate supervision, intervention and management of individual sows and piglets. These benefits however are offset by compromises to sow welfare. Crates limit the sow’s ability to perform the pre-farrowing sequence of nest building behaviour (Wischner et al., 2009), which is largely unmodified in domesticated sows and is considered to be biologically significant (Edwards, 2008; Baxter et al., 2011). The implications of this restriction are that the sow may experience stress, and display altered or misdirected behaviour (Weber, 1984; Damm et al., 2003).

Farrowing pens were designed to address the conflict between compromised sow welfare and high piglet survival observed in crate systems. Previous research has shown that piglet survival is highly variable in farrowing pen systems. Higher piglet mortality from birth to weaning in pen-based vs. crate-based farrowing systems has been reported in Cronin and Smith (1992), Blackshaw et al. (1994), Marchant et al. (2000) and Hales et al. (2014). Conversely, Weber et al. (2007), Pedersen et al. (2011) and KilBride et al. (2012) did not find a difference in piglet mortality from birth to weaning between farrowing pens and farrowing crates. The survival of piglets to weaning is one of the most important performance indicators of the farrowing and lactation period (Baxter et al., 2011). It is important that acceptable production levels are achieved in any new farrowing system, and that sow and piglet welfare is improved relative to that found in a farrowing crate.

Piglet mortality is an economic and a welfare issue. The majority of piglets that do not survive to weaning die within the first 3 days of life (Marchant et. al., 2000; KilBride et. al., 2012). The primary causes of death in this period are attributed to crushing by the sow and weakness/starvation (Dyck and Swierstra, 1987; Marchant et. al., 2000). Body movements performed by sows that can harm piglets have been described previously and have been shown to differ between farrowing systems e.g. farrowing crates and open pens (Weary et al., 1996; 1998). Temporarily confining sows for a short period of time around parturition can limit these dangerous body movements (Moustsen et al., 2013). Lower piglet mortality has been observed when sows were confined in a crate within a pen for 4 days after farrowing, relative to when sows were free to move unrestricted within a pen for the entire parturition and lactation period (Moustsen et. al. 2013). A crate in a pen used for a few days after parturition offers a compromise between confining the sow to reduce piglet mortality, whilst improving the sow's welfare during lactation period by allowing her more space to move around.

The aim of the present study was to compare the productivity of sows and piglets housed in farrowing crates or in combination pens (which confine sows in a crate from 3 days pre-farrowing until 4 days postpartum), and to determine whether the subsequent reproductive performance of sows was affected by the system (crate or combination pen) in which they had previously lactated.

Materials and methods

Animals and management

This study was carried out on a commercial farm in New Zealand with a herd of 1250 sows. Sows were Large White, Landrace, Duroc, and their crosses. Sow parity ranged from 1 to 10. Performance data were obtained from 394 sows (4706 live born piglets) in combination pens and 338 sows (3987 live born piglets) in crates over 14 farrowing batches. Sows were mixed into groups of 10 at weaning. Whilst housed in groups, sows were bred by artificial insemination after detection of oestrus. All sows were loose-housed indoors in groups of approximately 10 sows for the duration of pregnancy.

Sows from the first four batches (N = 111 in crates, 140 in pens) were weighed before being randomly allocated and moved to the farrowing accommodation 5 days before estimated parturition date (date of first mating + 115 days). Back fat measurements were taken at the P2 site (65mm down the left side from the midline at the level of the head of the last rib) once sows were in the farrowing accommodation. Sow pre-farrowing weight ('empty' weight) was calculated by subtracting the weight of the conceptus products from the total weight of the sow, using the following equation (NRC, 1998):

Weight of conceptus = (N total piglets born) x 2.28 kg.

Farrowing accommodation on the farm included 30 swing-sided combination farrowing pens and 256 farrowing crates. The pens were manufactured by Vissing Agro of

Denmark (Combi-Flex turn around farrowing pen). These pens measured 2.25 x 2.6m ($5.85m^2$ including creep area of $0.84m^2$) and were fitted with an internal farrowing crate that was temporarily used to confine sows pre-farrowing and in early lactation (Figure 3.1). The floor was fully slatted. Each combination pen had a feed trough in one corner of the pen and a bowl drinker that was accessible to the sow and piglets at all times. The triangular creep was covered and heated via a plastic floor pad that was set at 32°C at farrowing, and dropped 2ºC each week until weaning. Infrared lamps were not used in the combination pens. The creep areas had LED lights to attract piglets inside. The room had fan-assisted ventilation. For the first week post-farrowing room temperature averaged 25ºC in winter and 20ºC in summer.

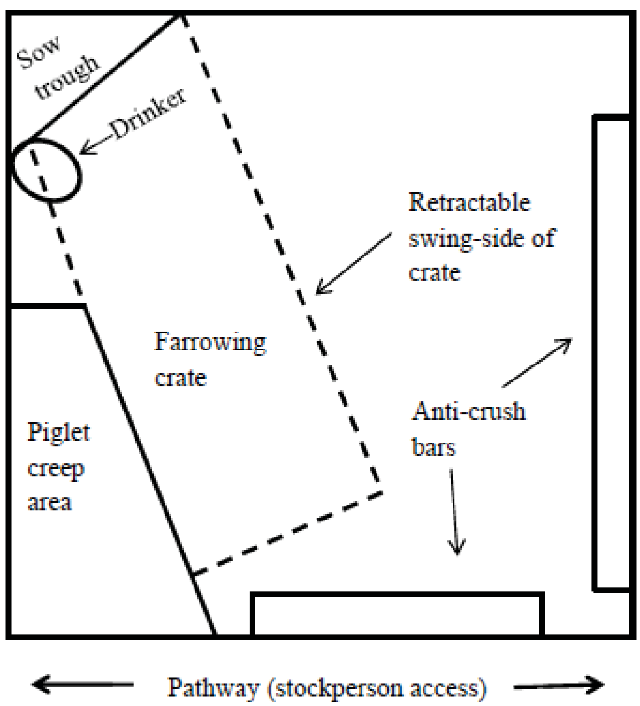

Figure 3.1. The farrowing pen design.

The farrowing crates were manufactured by Big Dutchman®. Crate width was adjustable to accommodate variable sow size. Crate length was 2.0m. The entire farrowing space (crate + creep and piglet areas) was approximately 3.84m^2 (1.6m x 2.4m). Each crate had a creep area with a heated plastic floor pad for piglets which was set at 32°C at farrowing, and dropped 2ºC each week until weaning. Infrared lamps provided supplementary heating for the first 5 days post-farrowing. The farrowing crates did not have covered creep areas. Room temperature for the first week post-farrowing averaged 25ºC in winter and 20ºC in summer.

Sows in the conventional crate treatment were confined from 5 days pre-farrowing until weaning. Sows in the combination pen system were confined inside the crate from 3 days pre-farrowing until the fourth day of lactation. This was a decision by farm management to allow safe handling of the sows and piglets by stockpersons and to minimise neonatal piglet mortality by restricting sow movement.

Parturition was induced in multiparous sows 113-114 days post-mating. This resulted in the majority of sows farrowing during staffed hours. All gilts farrowed naturally. A split dose of $PGF_{2\alpha}$ analogue EstroPLAN® (Parnell Laboratories Pty Ltd, equivalent to 250 μg cloprostenol/mL) was injected at the vulva-cutaneous junction. Staff members were present during the day from 0730 to 1600 to supervise farrowing sows.

Piglet processing took place ~24 hours after birth. This included teeth clipping, tail docking, recording total litter weight, administering an iron injection, and ear tagging. Litters were equalised within-system by cross-fostering piglets in the early postnatal period. Sows were evaluated and categorised by staff within 24 hours of farrowing based on the following: a demonstrated ability to rear a consistently high number of piglets; observations of behaviour; milking ability; and the teat number and teat presentation when lying. This determined the number of piglets a sow was given to rear.

Lactating sows were fed three times daily via a computer controlled liquid feeding system. The energy level of the lactation diet was 14.95 MJ DE/kg, at 16.67% CP. All sows and piglets in crates and combination pens had continuous access to water via a bowl drinker that was independent of the feeding system. Creep meal was provided for piglets from 7 days of age. Weaning occurred at approximately 28 days of age. All sows weighed pre-farrowing (N = 111 in crates, 140 in pens) were weighed again at weaning. Back fat measurements were taken again at the P2 site.

Although about 56 sows farrowed every week on the farm; the data was organised as 'batches' based on the 5-weekly cycle of the combination pens being emptied and reloaded. Thus every 5 weeks there was a batch of two treatment groups (combination pens vs. farrowing crates), and 14 batches were monitored in total, averaging 28 and 24 sows per batch in combination pens and farrowing crates respectively. Any sows with incomplete records or that did not complete a full lactation (due to illness or death etc.) were excluded from the data set.

If the observer was present during a squashing or potential/ actual injury event, intervention occurred in an attempt to save the piglet/s. This decision was made as the study took place on a commercial operation where normal staff protocol would be to intervene in these circumstances.

Statistical analysis

Performance data was extracted from the herd recording system EliteHerd® (Skorupski, 2003). In total, data was collected from 394 sows in the combination pens and 338 sows in farrowing crates between March 2012 and July 2013.

The following litter variables were analysed on a per litter basis: total born per litter, total born alive per litter, number weaned, weaning age, total weaning weight of litter, weaning weight/ piglet. This was performed using PROC GLM in SAS 9.2 using a linear model with fixed effects of the farrowing system, batch, sow parity (1,2,3,4,5,6,7,8, ≥ 9) and an interaction of farrowing system and batch.

Piglet mortality data (overall pre-weaning mortality, PWM) within batch and system was analysed with a logit model in SAS 9.2 (PROC GENMOD), with the interaction of farrowing system and batch as a fixed effect. There was insufficient data to perform a statistical analysis on every attributed cause of death apart from the 'laid on' or 'weakness/starvation' categories, thus other reasons for death were grouped together as 'other' for analysis purposes.

Reproductive data for sows included: the wean to service interval (WSI), farrowing interval, farrowing rate, repeat services, and removal rates. The WSI was calculated as the time (in days) taken for a sow to be mated after weaning. The farrowing interval was the time (in days) between the first farrowing and the next. The farrowing rate was calculated as the percentage of sows mated that farrowed. Repeat services were the percentage of sows that did not conceive to the first mating, and were mated again at the next oestrus. Removal rates are calculated as the percentage of sows that were removed from the herd (died or culled). Mating and farrowing records were analysed to calculate the reproductive performance of the subsequent litter that sows produced after being allocated to the two different treatments. Reproductive data was analysed in SAS 9.2 using PROC GENMOD with farrowing system, batch and parity as fixed effects.

Correlations were calculated for each farrowing system in SAS 9.2 using the following variables: total born per litter, total born alive per litter, number weaned, weaning age, total weaning weight of litter, weaning weight/ piglet, lactation weight loss, sow pre-farrowing weight, sow weight at weaning, sow pre-farrowing back fat, sow back fat at weaning, sow back fat loss and the wean to service interval.

Results

Litter variables

In the study, 8,693 piglets were born alive to 732 sows that farrowed. There was no statistical difference between the two treatments for total number of piglets born per litter, or the number born alive per litter (Table 3.1). However, the average litter size at weaning differed significantly between the two treatments. More piglets were weaned per litter from the crates (10.76 ± 0.065 piglets) than the combination pens (10.54 ± 0.052 piglets, P = 0.0024). There was also a significant effect of the batch upon the number of piglets weaned per litter (Table 3.1 and Figure 3.2). The number of piglets weaned decreased with increasing parity. The total number born and the number of piglets born alive per litter tended to increase up to the fourth parity, thereafter fewer piglets were born in successive litters.

The weaning weight of litters reared in combination pens was significantly higher than the litters reared in farrowing crates (Table 3.1, 82.70 ± 0.122 vs. 80.80 ± 0.138 respectively, $P<0.0001$). On average crated piglets were weaned slightly earlier. Although the difference in weaning age was numerically small (a difference of 0.45 days), this was a significant difference ($P = 0.0028$) between the two treatments. The weaning age however was included as a covariate when litter weaning weight was calculated.

The weight of sows (both pre-farrowing and at weaning) did not differ between treatments (Table 3.2; Figure 3.3). Sow parity was the only variable to have a significant effect on the weights of sows ($P<0.0001$). Sow pre-farrowing weight averaged 267.41 (± 2.70) kg in combination pens and 270 (± 3.40) kg in crates. Average weight loss during lactation was similar between treatments, at 14.88 (± 1.79) kg in combination pens and 14.58 (± 2.17) kg in crates. Average back fat loss was also similar during lactation at 3.40 (± 0.336) mm in crates and 3.28 (± 0.646) mm in combination pens.

Table 3.1. A comparison of litter performance parameters between sows housed in farrowing pens or farrowing crates (LSMEAN ±SE).

Productivity parameters	Pen LSMEAN (±SE)	Crate LSMEAN (± SE)	P(Parity)	P(System)	P(Batch)	P(System*Batch)
N Litters[1]	394	338	-	-	-	-
N Piglets born alive	4706	3987	-	-	-	-
Average sow parity	4.07 (± 0.114)	3.61 (± 0.127)	-	0.0075	0.0002	<0.0001
Total born per litter	13.01 (± 0.171)	13.14 (± 0.196)	<0.0001	0.5796	0.0532	0.3474
Total born alive per litter	11.87 (± 0.161)	11.91 (± 0.185)	<0.0001	0.8481	0.0643	0.3916
Total weaned per litter	10.54 (± 0.052)	10.76 (± 0.065)	<0.0001	0.0024	<0.0001	0.3658
Litter weaning weight	82.70 (± 0.122)	80.80 (± 0.138)	0.2255	<0.0001	<0.0001	<0.0001
Piglet weaning weight	7.67 (± 0.011)	7.50 (± 0.013)	0.1376	<0.0001	<0.0001	<0.0001
Lactation length	27.32 (± 0.103)	27.77 (± 0.119)	0.9632	0.0028	<0.0001	<0.0001
Overall piglet mortality[2]	-2.1724 (± 0.05) **10.23%**	-2.7331 (± 0.06) **6.10%**	-	<0.0001	0.0010	-
Piglet mortality to day 4	61.2%	69.57%	-	<0.0001	-	-
Piglet mortality after day 4	38.8%	30.43%	-	<0.0001	-	-

[1]After removal of sows with incomplete records.
[2]Calculated using Logit analysis, back transformed values are presented as a % in bold.

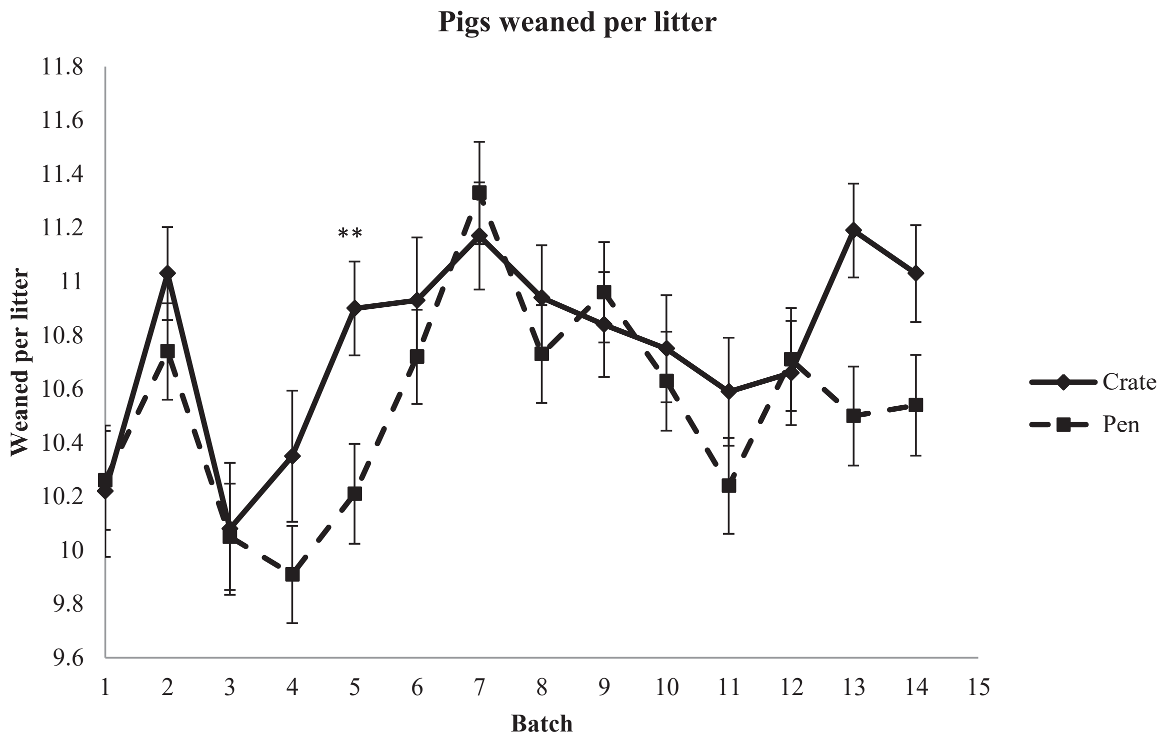

Figure 3.2. Comparison of pigs weaned per litter per batch (*N* = 14 batches of sows) in conventional farrowing crates and combination pens (LSMEAN ± SE). **P<0.01.

Subsequent reproductive performance of sows

A sow's subsequent reproductive cycle was not affected by the system in which sows lactated in this study (Table 3.2). A greater percentage of sows recently weaned from combination pens were removed before mating (10.70%) than sows from crates (7.10%), however this difference was not significant. There were no significant correlations in either housing system between the WSI and back fat loss during lactation. In crates, there was a weak negative correlation between the WSI and lactation weight loss (r = -0.2210, P < 0.05); however no significant correlation was apparent between these variables in penned sows.

Mortality

The accommodation used during lactation had a significant effect on overall piglet losses (Table 3.1). In the farrowing crates, 6.10% of piglets died before weaning whereas in the combination pens, 10.23% of piglets died on average. Whilst a higher percentage of pigs were killed due to savaging overall in the crate system (4.00%) than in the combination pens (1.82%), this difference was not significant. The median age of pigs killed by savaging was 1 day in crates and 0 days in combination pens. The cause of death and the proportions of piglets that died either before or after day 4 of lactation in each category are shown in Table 3.3. After day 4, a greater proportion of pigs were laid on in the combination pens compared to the crates. Similar proportions of piglets died as a result of weakness/starvation in both systems over the course of the lactation period.

A greater proportion of the piglets that died when they were older than 4 days of age, died in combination pens (38.8%) than farrowing crates (30.43%) (Table 3.1). Of the piglets that died as a result of being laid on after four days of age, a greater proportion was killed in the combination pens (42.5%) than in crates (30.8%) (Table 3.3) (P = 0.0093). Diarrhoea was responsible for the death of a greater proportion of piglets that were older than 4 days of age in combination pens than piglets of the same age reared in farrowing crates. However, overall there was no significant difference between combination pen and farrowing crate deaths attributed to diarrhoea.

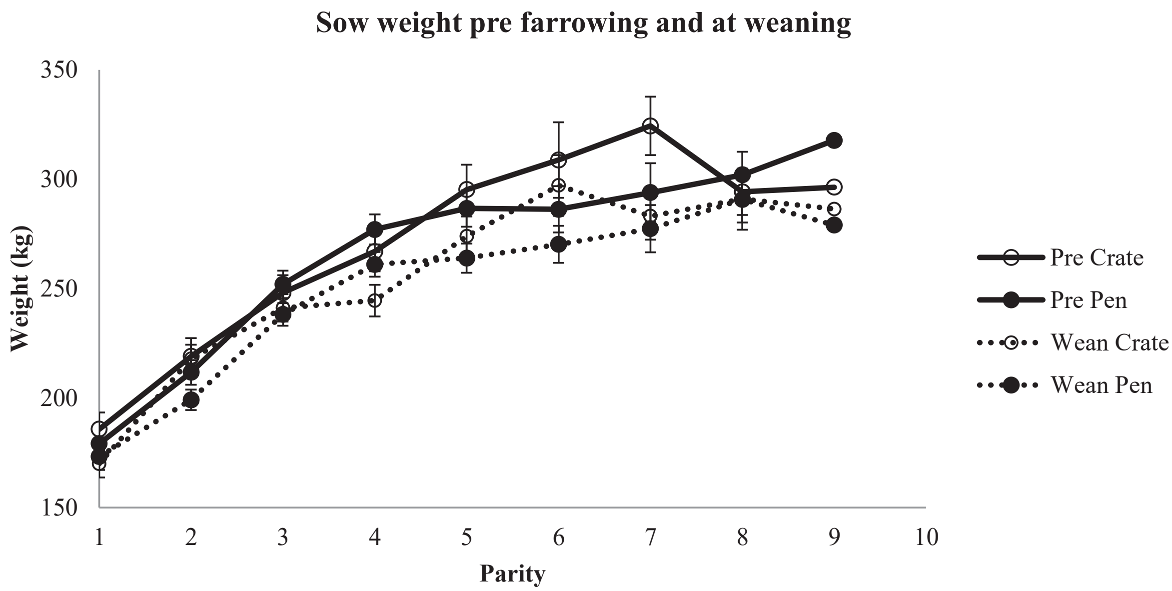

Figure 3.3. Empty weight and weaning weight of sows housed in either a combination pen or conventional farrowing crate (LSMEAN ± SE).

Table 3.2. A comparison of subsequent reproductive performance between sows housed in farrowing pens or farrowing crates (LSMEAN ±SE).

Reproductive performance	Pen LSMEAN (±SE)	Crate LSMEAN (± SE)	P(Parity)	P(System)	P(Batch)	P(System*Batch)
N sows weaned	383[1]	338	-	-	-	-
Removed before mating	41 (10.70%)	24 (7.10%)	-	0.0938	-	-
Mated ≤6 days post weaning	307 (89.77%)	279 (88.85%)	-	0.7054	-	-
Mated ≥7-29 days post weaning	35 (10.23%)	35 (11.15%)	-	0.7054	-	-
Repeat matings	25 (7.31%)	24 (7.64%)	-	0.8711	-	-
Wean-service interval (days)	7.61 (± 0.806)	7.85 (± 0.818)	0.5649	0.7384	0.2761	0.3879
Removed after mating	21 (6.14%)	29 (9.24%)	-	0.1381	-	-
Removed overall	62 (16.19%)	53 (15.68%)	-	0.8527	-	-
N sows mated that farrowed	321 (93.86%)	285 (90.76%)	-	0.1381	-	-
Farrowing interval (days)	149.45 (±0.403)	149.65 (±0.446)	0.4952	0.9388	0.3705	0.0702
Pre-farrowing weight (kg) (N = 251)	267.41 (± 2.70)	270.32 (± 3.40)	<0.0001	0.4779	0.0010	0.4022
Weaning weight (kg) (N = 251)	251.55 (± 2.44)	256.11 (± 2.84)	<0.0001	0.1913	0.0136	0.1989
Lactation weight loss (kg) (N = 251)	14.88 (± 1.79)	14.58 (± 2.17)	0.1427	0.9091	<0.0001	0.2285
Pre-farrowing back fat (mm) (N = 133)	15.58 (± 1.025)	15.28 (± 0.533)	0.0081	0.8208	0.0180	-
Weaning back fat (mm) (N = 133)	12.29 (±0.857)	11.89 (±0.445)	0.0001	0.7020	0.4194	-
Lactation back fat loss (mm) (N = 133)	3.28 (±0.646)	3.40 (± 0.336)	0.3177	0.8827	0.0004	-

[1]After removal of sows with incomplete records.

Table 3.3. The % of piglets that died before or after day 4 in farrowing pens and conventional farrowing crates, classified by reason for death.

Reason	Pen		Crate	
	< 4 days (%)	> 4 days (%)	< 4 days (%)	> 4 days (%)
Laid on	57.50[a]	42.5[b]	69.2[c]	30.8[d]
Weakness/Starvation	85.40[a]	14.6[b]	83.33[a]	16.67[b]
Other[1]	47.80[a]	52.2[a]	47.4[a]	52.6[a]
Diarrhoea	28.60	71.40	60.00	40.00
Splay leg	100.00	0.00	100.00	0.00
Legs	14.30	85.70	0.00	100.00
Deformed	100.00	0.00	80.00	20.00
Unknown	25.00	75.00	16.70	83.30
Savaged	70.00	30.00	63.60	36.40

[1]The 'other' category is the sum of the causes of death that were not attributed to being laid on or caused by weakness/starvation.
[a,b,c] Values with differing superscript differ significantly within each reason across each age category ($P \leq 0.05$).

Discussion

The main differences in productivity observed between the accommodation systems used during lactation were the litter size at weaning and the piglet mortality rate. Many factors can influence piglet mortality including birth weight (Baxter et al., 2009); total piglets born (Weber et al., 2007), management and stockmanship (Kirkden et al., 2013), sow parity (Andersen et al., 2011), environmental conditions (Pedersen et al., 2013a) and the farrowing accommodation design (Pedersen, 2013b). As this study took place on one farm, the majority of these factors were the same with the exception of the accommodation used for sows and piglets during lactation.

Fewer pigs were weaned from litters reared in combination pens (10.54 pigs per litter) than from litters reared in crates (10.76 piglets weaned per litter). This was due to significantly higher pre-weaning piglet mortality (PWM) in the combination pens.

Despite the difference in terms of numbers weaned per litter, the weaning average for combination pens was equal to the New Zealand pork industry average (10.50 per litter, Welch, 2012). Furthermore, the survival of piglets to weaning in farrowing crates in this study is very high (PWM of 6.10%) when compared to the New Zealand industry average of 13.5% PWM (Welch, 2012). The pre-weaning mortality rate of piglets in combination pens (10.23%) was also lower than the industry average.

A greater proportion of piglets aged 4 days or older died in combination pens than in farrowing crates. Once the temporary crate was opened on the fourth day of lactation, sows had access to the entire area within the pen, except the creep area. This period is a time of significant adaptation for the sow and perhaps the litter. More space for the sow enables a wider repertoire of postures and movements. The piglets are now less protected from dangerous and sudden lying down movements made by the sow. When comparing piglet mortality between a restrictive environment (crate) and a less restrictive environment (combination pen), piglet mortality was proportionally higher once the sows were no longer restricted by a crate. As such, piglet deaths caused by crushing were higher in penned sows than crated sows after the fourth day of lactation. In a previous study by Marchant et al. (2000) larger numbers of deaths caused by crushing were recorded once sows were released into a communal area following 7 days in a crate. More recently, Moustsen et al. (2013) found that restraining sows in a crate for 4 days postpartum reduced piglet mortality compared to sows that were loose within a pen with no restriction during parturition and lactation.

According to Baxter et al. (2011), the minimum space required for a sow to turn around unimpeded in $4.9m^2$. This may also be the minimum space needed by the sow to group piglets together before lying down, in an attempt to prevent accidental crushing. Other studies have found that when the size of the farrowing pen measures $5m^2$ and above, piglet mortality is similar to that observed in farrowing crates (Weber and Schick, 1996; Cronin et al., 2000; Stabenow and Manteuffel, 2002; Weber et al., 2007). In each of these studies, piglet mortality was 13.5% - 15.2%, 13%, 16.9%, and 13% respectively in farrowing pens, with no significant difference reported in farrowing crates. In our study, the pens provided the sow with exactly $5m^2$, and piglet mortality was still found to be significantly higher in combination pens (10.23%) than in farrowing crates (6.10%). This was similarly observed by Hales et al. (2014), who found piglet mortality was higher in pens than in crates in three different herds which had pen sizes of $5.2m^2$ (15.8% piglet mortality), $5.4m^2$ (14.2% piglet mortality) and $6.3m^2$ (11.7% piglet mortality). As only one pen design was compared in the current study, it would be difficult to determine whether it was the size of the pen specifically that was responsible for increased piglet mortality. However piglet mortality in the present study was still much lower than what was reported in previous experiments. This indicates that the size of the pen is only one factor that may influence the survival of piglets to weaning, including sow behaviour (Damm et al., 2005), good management and skilled stockmanship (Hemsworth et al., 1994.)

There was a significant effect of the batch on the number of piglets weaned per litter. A likely explanation for this could be the adjustment of staff to the new housing system that only utilised a crate for four days postpartum. This also includes the training of new staff, which occurred between batches 9 to 11 (Figure 3.2) Changes in everyday management were adopted over time to optimise sow and piglet performance in the combination pens. Parity also had a significant effect on the total number of piglets born as well as total weaned per litter. The total number born per litter increased with each parity up to parity 4. The number weaned consistently decreased with each parity thereafter. This relationship between parity and litter size has been reported elsewhere (Hughes 1998; Milligan et al., 2002; Quesnel et al., 2008).

Our results show that piglets weaned from the combination pens were heavier (7.67 ± 0.011 kg) than those weaned from farrowing crates (7.50 ± 0.013 kg). Piglet weight gain and the number of piglets weaned in either farrowing pens or farrowing crates was compared by Moustsen and Poulsen (2004). They found no difference in the numbers of piglets weaned; but piglets reared in pens were an average of 0.3 kg heavier at weaning than those reared in crates. Similar findings were reported by Oostindjer et al. (2010) who examined the effect of the farrowing environment on piglet performance before and after weaning. They found that in the period from 15 days after birth until weaning, piglets reared in a pen had greater growth rates than those reared in a crate. It has been suggested that during the latter half of the lactation period there is an increase in solid feed intake by piglets, which may be stimulated more in piglets reared in farrowing pens (Oostindjer et al., 2010).

An alternative explanation for heavier piglets at weaning could be the nursing duration and/or nursing frequency of sows. Sow and piglet behaviour and productivity in a family pen farrowing system or farrowing crate was studied by Arey and Sancha (1996). In this study, sows in one treatment group farrowed in crates. In the other treatment sows were kept in a communal area in groups of four with voluntary access to straw bedded farrowing pens (family pen system). They reported a higher percentage of true nursing bouts with milk let down, and a longer duration of nursing bouts in the family pen system than in the crate system. The higher frequency of true nursing bouts may reflect increased sow comfort in a pen system as the result of having more space. In the present study, sows in combination pens elicited more nursing vocalisations than sows in crates during the same period (Chidgey et al., 2013). This may suggest that there are more frequent nursing bouts in penned sows.

To date, no reported data has examined the carry-over effect of the farrowing and lactation accommodation on a sow's later reproductive performance. In the current study, no significant effect was found regarding the accommodation used during lactation. Weight loss during lactation can have a significant influence upon the subsequent reproductive performance of sows. Excessive lactation weight loss (above 10 kg in gilts and 22 kg in sows, Lawlor, 2012) has been shown to extend the WSI, reduce pregnancy rates and reduce embryonic survival (Bilkei, 1995; Close and Mullan, 1996). A weight loss of more than 10% has been reported to significantly depress the subsequent reproductive performance of sows (Thaker and Bilkei, 2005). The WSI increased when lactation weight loss increased above 5% in primiparous sows. No detrimental effect was observed in multiparous sows (parity 2 – 5) until weight loss reached above 10% (Thaker and Bilkei, 2005). In primiparous sows, lactation weight losses of over 10% had negative effects on subsequent farrowing rates ($P < 0.05$) and on the total pigs born in the consequent litter ($P < 0.001$). In the present study, there were no significant correlations between the WSI and weight loss during lactation. Sows in combination pens and farrowing crates experienced low lactation weight losses averaging 5.56% and 5.39% respectively. Thus the absence of any significant effect on sow reproduction may therefore be attributed to this observation across both housing systems.

Conclusion

This study found that piglet mortality was higher and fewer pigs were weaned per litter in combination pens compared to farrowing crates. Productivity was however still acceptable when compared to New Zealand industry averages. After piglets reached four days of age, the penned sows were let out of their crates. A greater proportion of their piglets died after this period compared to those reared by sows that remained in crates until the end of lactation. The current study did not confirm any carry-over effect of the lactation system on a sow's subsequent reproductive performance. It is important that future studies continue to establish the potential effects that a farrowing crate alternative may have on production.

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Chapter 4

Observations of sows and piglets housed in farrowing pens with temporary crating or farrowing crates on a commercial farm

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Abstract

Alternatives to farrowing crates have been developed to improve sow welfare. These alternative farrowing systems have been designed to provide more space, allowing sows greater freedom of movement during lactation. This experiment was part of a larger study comparing sow and piglet performance and behaviour in two farrowing systems. In one farrowing system, sows were housed in crates from 5 days pre- until 28 days post-farrowing ($N = 15$ sows and 187 piglets born). In the other farrowing system, sows were initially housed in crates from 3 days pre-farrowing until day 4 of lactation, after which they were loose within a pen until weaning at 28 days ($N = 16$ sows and 178 piglets born). The objective was to compare the behaviour of sows and piglets in crates and pens during days 1 – 6 post-farrowing. Sows in both systems spent the majority of their time lying (88 – 94% of the time in crates, and 72 – 94% of the time in pens) and there was no difference between crates and pens for the amount of time sows spent standing ($P = 0.20$), sitting ($P = 0.63$), or lying ($P = 0.45$) during days 1 – 6. Sows in pens investigated ($P = 0.03$) and touched ($P < 0.01$) their piglets more than sows in crates. Piglets in pens tended to spend less time inactive in open areas of the farrowing space compared to piglets in crates ($P = 0.04$). The current study demonstrated that the farrowing system design can influence sow behaviour, with pens allowing for more interactions between sows and their piglets.

Keywords: Sow behaviour; Piglet behaviour; Farrowing crates; Farrowing pens

Introduction

In pig production, farrowing crates are used to reduce piglet mortality (Edwards and Fraser, 1997; Edwards, 2002) A sow's movement is restricted in a crate, which reduces the incidence and frequency of dangerous posture changes which have been implicated in crushing-related piglet mortality (Melisova et al., 2014). In New Zealand, sows may be confined in farrowing crates for no more than 5 days before giving birth and may remain confined for a maximum of four weeks thereafter (Anon, 2010). Crates limit a sow's movements to standing, sitting, lying, and rolling onto either side. The limited mobility and restricted behavioural displays of crated sows has led to concerns for their welfare.

Pen-based farrowing systems have been developed to address these welfare concerns through providing more space, which allows sows to turn around and interact more with their piglets (Bradshaw and Broom, 1999). Farrowing pen systems can be 'free farrowing', where no crating occurs, or temporary crating may be used where sows are confined in a farrowing crate during parturition and for 3 – 7 days during early lactation. Sows housed in pen-based systems can lie down and roll onto their side with greater ease than crated sows (Gu et al., 2011) and they may be less cautious when changing posture, rolling over onto their side faster and twice as often as crated sows (Blackshaw et al., 1994; Weary et al., 1996a). It has been reported that pre-weaning mortality of piglets in farrowing pens with and without temporary crating is greater than in farrowing crates (Marchant et al., 2000; Moustsen et al., 2013; Hales et al., 2014; Chidgey et al., 2015). Alternative farrowing systems should ideally improve upon sow and piglet welfare in farrowing crates, without compromising piglet survival.

This paper is part of a larger study comparing sow and piglet production, sow reproductive performance, and sow and piglet behaviour in farrowing crates and pens with temporary crating. Sow reproductive performance and sow and piglet production data have been reported previously, where it was found that piglet mortality in pens (10.2%) was significantly higher than in crates (6.1%) (Chidgey et al., 2015). The aim of the present study was to compare sow and piglet behaviour between two different housing systems during the first 6 days of lactation. Sows in crates were confined from 5 days pre- until 28 days post-farrowing. Sows in pens were in a crate from 3 days pre- until 4 days post-farrowing, after which they were loose in the pen until weaning at 28 days.

Materials and methods

Animals and management

This study was carried out at a 1250 sow commercial pig farm in New Zealand with the approval of the Massey University Animal Ethics Committee (protocol 12/36). Sow breeds were Large White, Landrace, Duroc, and their crosses, and sows ranged from parity 2 to 10. Sows were mixed into groups at weaning, bred by artificial insemination, and housed indoors in groups of 10 for the duration of pregnancy. The data were organised as ‘batches’ based on the 5-weekly cycle of the farrowing pens being emptied and reloaded. Observations were carried out on 31 randomly selected sows over 4 batches. All sows were familiar with farrowing crates only. Post-farrowing observations of sows and piglets were recorded from day 1 to day 6 of lactation. Sows were not observed during the day of farrowing (day 0). One observer recorded all of the behavioural observations throughout the study. Sows and piglets were not observed while staff performed husbandry tasks. These included piglet processing, vaccinations, fostering, and miscellaneous treatments.

Sows were moved into the farrowing accommodation 5 days before the estimated parturition date (date of first mating + 115 days). Sows in farrowing crates were confined from 5 days before estimated parturition date until weaning (approximately 28 days after farrowing). Sows in the farrowing pens were loose for the first two days and then confined in a crate, from day 3 before parturition until day 4 of lactation. The length of confinement pre-farrowing was decided by farm management. The decision to release sows from their temporary crates on day 4 was based on the knowledge that the majority of piglet deaths occur in the first three days post-farrowing thus confinement of sows to day 4 would aid supervision and intervention at this critical period. In addition, most of the piglet husbandry tasks, including fostering, were completed by day 4 post-farrowing thus after this period, routine management was not impeded by the sow being loose.

Parturition was induced in all sows 113-114 days post-mating. A split dose of $PGF_{2\alpha}$ analogue EstroPLAN® (Parnell Laboratories Pty Ltd, equivalent to 250 μg cloprostenol/mL) was injected at the vulva-cutaneous junction. Stockpersons were present in the farrowing rooms each day from 0730 h to 1600 h to supervise farrowing sows.

Piglet processing took place ~24 h after birth. This included teeth clipping, tail docking, recording total litter weight, administering an iron injection, and ear tagging. Piglets were cross-fostered within-system in the first 48 hours post-farrowing to equalise litter sizes at 11 – 12 piglets per sow.

On-farm farrowing accommodation included 30 farrowing pens and 256 farrowing crates. Every 5 weeks, a batch of 56 sows was randomly allocated to farrow in either farrowing pens or farrowing crates. The farrowing pens were manufactured by Vissing Agro of Denmark (Combi-Flex turn around farrowing pen); they measured 2.25 x 2.6m (5.85m^2 including creep area of 0.84m^2) and were fitted with an internal farrowing crate (2.1m in length, adjustable width) that was temporarily used to confine sows pre-farrowing and in early lactation. The feed trough was located in one corner of the pen next to a bowl drinker that was accessible to the sow and piglets. The covered triangular creep had a heated plastic floor pad that was set at 32°C at farrowing and reduced by 2 ºC each week until weaning. The creep had LED lights to attract piglets inside.

The farrowing crates were manufactured by Big Dutchman®. Crate width was adjustable to accommodate variable sow size, and crate length was 2.0m. The entire farrowing space (crate + creep and piglet areas) was approximately 3.84m^2 (1.6m x 2.4m). Each crate had a heated plastic floor pad for piglets which was set at 32°C at farrowing, and dropped 2 ºC each week until weaning. Infrared lamps were fixed above the heated floor pad to provide supplementary heating for the first 5 days post-farrowing in crates. Both farrowing systems had fully slatted flooring. Farrowing room temperatures for both systems averaged 25ºC in winter and 20ºC in summer during the first week post-farrowing. Both systems had fan-assisted ventilation.

In both systems, lactating sows were fed three times daily via a computer controlled liquid feeding system. The energy level of the lactation diet was 14.95 MJ DE/kg at 16.67% crude protein. Creep meal was provided for piglets from 7 days of age. Weaning occurred at approximately 28 days of age.

Observations of sows and piglets

The day of farrowing was day 0. Post-farrowing observations were recorded for days 1, 2, 3, 4, 5 and 6. Sows were fed twice during observation hours at 0900 h and 1500 h. No observations were recorded from 15 minutes before to 20 minutes after feeding. Observations began at 0800 h after a habituation period of 10 minutes. Sows and piglets were observed during four sessions throughout each day: AM1 (0800 h – 0845 h), AM2 (0920 h – 1100 h), PM1 (1230 h – 1445 h) and PM2 (1520 h – 1600 h). On day 4 sows in pens were let out of their crates approximately one hour before AM1. This allowed sows to adjust to their altered surroundings before observations began. Sow and piglet observations (Table 4.1) were sampled using fixed interval scan sampling. Each day 100 observations lasting 30-seconds each were recorded for four sows and their litters per farrowing system. During each 30 second period, sow and piglet behaviour, piglet location and sow posture were recorded. Therefore during one 30 second period, all of the variables that occurred during that time were recorded as they were not mutually exclusive. At each sampling period, the behaviour and location of all piglets in each litter was documented. Each sow and litter were observed 30 seconds immediately after the previous litter, thus every two minutes a full rotation of four sows was completed. Sows were observed in the same sequence within one system.

All observations were documented on recording sheets in real time, or recorded on video cameras. Sows in the two farrowing systems were housed in different rooms. If an overlap occurred due to sows in different systems farrowing within 6 days of one another, video cameras continuously recorded 4 sows in one room/system throughout the day. The video footage was then reviewed by the same observer and scan sampled at the same interval as the real time observations. Data were identified by source (real time or video). The variables chosen for observation of sows and piglets were based on a review of the literature (Arey and Sancha, 1996; Cronin et al., 1996) and are described in the following categories (Table 4.1):

- Sow observations: General behaviour
- Piglet-directed behaviour
- Sow posture
- Pen/crate-directed behaviour
- Sow-directed behaviour

Piglet observations:

- Piglet location
- General piglet behaviour

Table 4.1. Parameters recorded during observations of sows and piglets.

Observation parameter	Description
General sow behaviour	
Eating	Lowering head into the feeder and ingesting food.
Drinking	Drinking water
Vacuum chewing	Repetitive chewing without food in the mouth
Grunt	Sow vocalises
Alarm call	Sow vocalises: alarm/ warning 'bark'
Nursing	Milk let-down, sow is lying laterally and piglets are suckling.
Piglet-directed behaviour by sows	
Investigate piglet/s	Sow turns towards and sniffs/ looks at piglet/s
Vocalise at piglet/s	Grunting at piglet (excludes nursing)
Touch Piglet/s	Sow intentionally touches piglet i.e. with the nose
Nursing vocalisations	Low-pitched rhythmic signal for piglets to suckle; vocal response to udder stimulation by piglets
Sow posture and posture changes	
Standing	Maintaining an upright body position with 4 legs supporting sow body weight
Sitting	Partly erect on front legs with the hindquarters in contact with the floor
Ventral lying	Lying on sternum/belly, udder is partially or totally obscured
Lateral lying	Lying flat on one side with a shoulder on the floor and udder exposed
Descending movements (1)	Sow lays down from standing position
Descending movements (2)	Sow lays down from a sitting position
Ascending movements	Sow sits up from lying down, stands from lying, or stands from sitting position
Sow location in pen	
Against wall/ surface	Sow is lying against a wall or surface
Free of wall/surface	Sow is lying in the middle of the pen without touching a wall/surface
Pen/crate-directed behaviour by sows	
Pawing	Sow scrapes at floor with front leg/s
Rooting floor	Touching the floor with the snout ('digging'), accompanied by head movement
Biting fixture	Biting at any of the fixtures within the crate or pen (e.g. bars, trough)
Nosing fixture	Nasal contact, 'rubbing' fixtures of the pen/crate
Sow-directed behaviour	
Alert	Turn towards, lifting head towards another sow
Investigate	Approaches another sow with interest, touches another sow, changes posture to view another sow
Vocalise	Sow grunts at another sow (non aggressive)
Agonistic	Aggressive/retaliatory behaviour towards other sows (e.g. bite, vocal 'bark')
Piglet location	
Udder (active/inactive)	Piglet is at the udder (sleeping or lying = inactive; teat seeking, massaging = active)
Adjacent	Piglet is within 0.1m of the sow, not at the udder or in the creep
Creep (active/inactive)	Piglet is in the creep area (sleeping/ lying = inactive; standing/sitting/walk = active)
Underneath	Piglet is under the sow when sow is standing
Open (active/inactive)	Not in the above locations ((sleeping/ lying = inactive; standing/sitting/walk = active)
Piglet behaviour	
Massage	Piglet is massaging the sow's udder
Suckling	Piglet is suckling from a teat
Drinking	Drinking water, not suckling
Vocalising at sow	Piglet vocalising at the sow (not while suckling)
Vocalising at littermate/s	Grunting at a fellow littermate while in close proximity and/or with eye contact
Agonistic	Piglet attacks (incl. Biting and tail biting), and/ or retaliates to an attack
Chewing sow	Piglet bites/chews the sow (not while suckling)

Piglet behaviour was categorised as ‘inactive’ or ‘active’ in an effort to quantify their activity level. Play behaviour was incorporated within ‘active’ displays without specifically defining it as playing. Sow-directed behaviour was the combination of four activities (alert, investigate, vocalise and agonistic). Though sows were housed separately, interactions between neighbouring sows were not completely prevented. If the observer was present during an overlying or a potential or actual injury event, intervention occurred in an attempt to save the piglet. This decision was made as the study took place on a commercial farm where normal staff protocol would be to intervene in this circumstance.

Statistical analysis

In total, 16 sows and 178 piglets (born) were observed in the farrowing pens, and 15 sows and 187 piglets (born) were observed in farrowing crates. A total of 18,600 individual time periods were observed (31 sows and litters x 6 observation days x 100 30 – second observation periods). At each time period 41 different behaviours (Table 4.1) were recorded for sows and piglets simultaneously during the study. For the analysis, the sow and litter were used as the statistical unit. The binomial sow data was analysed after a logit transformation (PROC GENMOD) performed in SAS 9.2. The model included the fixed effects of ‘farrowing system’, ‘day of observation’, and the interaction between farrowing system and day of observation, with a random effect of ‘sow’. ‘Sow’ was used as a repeated subject in the model. The logit Lsmeans were back-transformed to calculate the % of scans during which each parameter was observed. Piglet data were first averaged per litter for each parameter. The means were then analysed after a logit transformation (PROC GENMOD) with the fixed effects of 'farrowing system', 'day of observation', and the interaction between farrowing system and day of observation. 'Sow' was a random effect and a repeated subject in the model. The Lsmeans were back-transformed to calculate the % of scans during which each parameter was observed.

Results

Observations of sow behaviour and posture

Sow behaviour and posture was compared between the two farrowing systems on each day of observation. Nursing vocalisations were more often performed by sows in pens than sows in farrowing crates during days 1 – 6 post-farrowing ($P = 0.04$, Table 4.2). Sows in pens also investigated ($P = 0.03$) and touched ($P = 0.04$) their piglets more than sows in farrowing crates (Table 4.2). Sows in pens performed more sow-directed behaviour than those in crates ($P_{system} < 0.01$, Table 4.2), and this behaviour increased in penned sows once they were loose from day 4 onwards. Penned sows also rooted at the floor more than sows in crates during days 1 – 6 post-farrowing ($P_{system} = 0.03$, Table 4.2).

Table 4.2. Sow behaviour and posture during days 1 – 6 post-farrowing (% back transformed from Logit Lsmean).

Parameter	System	Day						System	Day	System × day
		1	2	3	4	5	6			
Standing	Crate	2.9	7.3	9.5	6.9	9.3	9.0	0.06	0.01	0.20
	Pen	4.5	9.5	8.5	15.6	25.6	15.9			
Sitting	Crate	1.5	3.9	3.3	4.7	4.7	4.6	0.61	0.20	0.63
	Pen	2.2	4.1	5.8	2.4	2.5	2.4			
Lying	Crate	94.4	90.5	89.9	92.6	88.9	88.1	0.06	<0.05	0.45
	Pen	93.8	88.1	86.7	80.2	71.9	79.4			
Nursing	Crate	2.3	3.3	3.0	3.7	3.2	3.1	0.38	0.47	0.55
	Pen	2.6	2.6	2.4	2.6	3.1	3.1			
Nursing vocal	Crate	3.1	3.9	3.9	5.1	4.1	3.4[a]	0.37	0.08	<0.05
	Pen	4.4	2.7	3.9	4.6	5.6	6.2[b]			
Vocalise at piglet	Crate	7.9	9.5	8.3	6.7	5.9	6.3	0.18	0.96	0.07
	Pen	8.1	7.7	8.4	9.6	12.0	9.6			
Investigate piglet	Crate	2.7[a]	7.3	7.7	8.9	8.3[a]	8.9	0.21	0.01	0.03
	Pen	8.2[b]	6.4	7.9	10.2	12.8[b]	8.9			
Touch piglet	Crate	3.7[a]	7.5	8.0	7.5	8.1	8.5	0.60	0.04	0.04
	Pen	7.2[b]	5.3	6.4	8.7	11.6	8.3			
Sow-directed	Crate	0.4	0.5	1.7	1.3	1.0	0.7	<0.01	0.02	0.35
	Pen	2.0	2.1	2.9	4.7	7.9	5.3			
Vacuum chewing	Crate	2.3	12.4	15.5	19.2	19.2	21.9	0.36	<0.01	0.81
	Pen	3.4	9.6	9.7	11.1	15.4	15.4			
Nosing	Crate	0.8	3.9	5.1	6.1	4.7	4.5	0.65	0.02	0.15
	Pen	2.4	3.1	3.3	6.5	6.4	4.7			
Pawing	Crate	0.1	0.3	0.3	0.3	0.7	0.5	0.45	0.22	0.37
	Pen	0.1	1.3	0.4	0.1	0.9	0.9			
Biting	Crate	0.2	2.3	3.2	2.6	2.9	1.9	0.17	0.02	0.52
	Pen	0.5	1.1	0.8	1.6	1.6	1.6			
Rooting	Crate	0.7	1.2	1.2	0.9	1.1	1.3	0.03	0.25	0.16
	Pen	1.0	2.0	1.6	2.6	6.8	2.3			

[a,b]Values with different superscripts differ significantly ($P < 0.05$) between farrowing systems within the same day.

Once loose, sows in pens were more active. They spent more time standing and rooting the floor, and less time lying (Table 4.2). They also performed more piglet-directed behaviour (investigating, touching and vocalising towards piglets) once released from the temporary crate (Table 4.2).

The day of observation had a significant effect on several parameters. Over days 1 – 6 post-farrowing, sows in both systems decreased the amount of time spent lying ($P_{day} = 0.04$, Table 4.2) and were standing ($P_{day} = 0.01$, Table 4.2), vacuum chewing ($P_{day} < 0.01$, Table 4.2), nosing ($P_{day} = 0.02$, Table 4.2) and biting fixtures ($P_{day} = 0.02$, Table 4.2) more often. Investigating and touching piglets also tended to increase over time.

Piglet behaviour

On day 1 post-farrowing, piglets in pens were more active in open areas (8.0%, Table 4) than piglets in crates (5.0%, Table 4.3). Piglets in pens tended to spend less time inactive in open areas compared to those in crates ($P = 0.04$, Table 4.3). On days 5 and 6 post-farrowing, when the sow was loose, piglets in pens spent significantly less time inactive in open areas than piglets in crates (Table 4.3). There were no other differences in piglet observation parameters between systems.

Table 4.3. Piglet behaviour and location during days 1 – 6 post-farrowing (% back transformed from Logit Lsmean).

Parameter	System	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	System	Day	System × day
Udder active	Crate	27.7	22.3	20.2	20.5	20.3	21.9	0.25	0.14	0.42
	Pen	24.8	19.2	21.7	23.0	24.9	27.1			
Udder inactive	Crate	27.0	19.0	10.4	11.0	9.8	11.3	0.32	0.01	0.87
	Pen	7.5	19.2	14.0	9.4	11.6	16.8			
Creep active	Crate	3.5	6.0	7.1	5.9	6.2	7.3	0.11	0.03	0.46
	Pen	3.8	5.5	4.4	4.5	4.4	5.5			
Creep inactive	Crate	32.8	39.4	46.0	46.2	42.7	38.1	0.32	0.06	0.84
	Pen	31.8	48.9	50.3	49.2	48.4	39.4			
Open active	Crate	5.0[a]	5.8	8.5	7.5	9.3	10.4	0.83	0.01	0.02
	Pen	8.0[b]	5.0	6.7	9.1	9.3	8.6			
Open inactive	Crate	3.9	7.5[b]	7.7	8.9	11.8[b]	11.1[b]	0.08	0.33	0.04
	Pen	4.0	2.1[a]	2.9	4.8	1.4[a]	2.7[a]			
Massage	Crate	26.4	20.7	18.5	19.0	19.1	20.9	0.60	0.06	0.34
	Pen	22.6	16.4	19.9	21.3	22.8	25.2			
Sucking	Crate	26.4	20.7	18.5	19.0	19.1	20.9	0.74	0.19	0.92
	Pen	23.6	16.4	19.9	21.3	22.8	25.2			
Vocal sow	Crate	0.5	0.6	0.5	0.6	0.5	0.8	0.05	0.5	0.80
	Pen	0.8	0.9	0.8	0.7	0.7	0.9			
Vocal pig	Crate	1.2	0.8	0.8	0.8	0.8	1.0	0.88	0.09	0.26
	Pen	0.9	0.8	0.7	1.5	0.7	1.2			

[a,b]Values with different superscripts differ significantly ($P < 0.05$) between farrowing systems within the same day.

The day of observation was a significant effect for some piglet observation parameters in both systems. Inactive behaviour at the udder tended to decrease with time ($P_{day} = 0.01$, Table 4.3), whereas active behaviour in the creep ($P_{day} = 0.03$) and active behaviour in open areas ($P_{day} = 0.01$) tended to increase over time in both systems.

Discussion

Observations of sow behaviour and posture

Even on days 1, 2 and 3 post-farrowing when sows in both systems were crated, more sow-directed behaviour was performed by sows in pens compared to those in crates. This may have been a carry-over effect of the pre-farrowing period. When the sows were first moved into pens from group housing they had use of the full area of the pen for two days before being confined in a crate. Thus, the sows in pens could engage in affiliative behaviours with neighbouring sows during these two days. Auditory, visual and olfactory communication can occur in sows housed in dry sow stalls, and would also be possible between sows in adjacent farrowing crates (McGlone et al., 2004). While loose in pens, neighbouring sows can engage in the aforementioned communication in addition to physical contact (i.e. naso-naso). Individually housed sows can still influence the behaviour of their neighbours (Jensen, 1984; Appleby et al., 1989; Barnett et. al., 1991; Mendl et al., 1993). Though sow-directed behaviour did differ between crates and pens, this behaviour was rarely observed in either treatment during days 1 - 3. Thus the ethological implication of this result is not likely to be significant.

During days 1 – 6 post-farrowing there was no difference in the amount of time that sows in crates and pens spent lying. Sows spent most of their time at rest, ranging from 94% - 88% of the time in crates, and 94% - 72% of the time in pens during days 1 – 6. Behavioural passivity is common in sows for 24 – 48 hours after parturition (Johnson and Marchant-Forde, 2009) irrespective of the environment in which they farrow. For example, even sows in semi-natural conditions spent 90% of their time during the first 2 days post-farrowing lying in their nest (Jensen, 1986). Low activity after parturition may be a behavioural adaptation that reduces accidental crushing of piglets. The activity level of loose-housed sows has been shown to increase significantly after the first week post-farrowing (Valros et al., 2003). These findings suggest that sows are not motivated to be particularly active soon after parturition; therefore confinement during 3 – 4 days post-farrowing may not compromise the sow’s welfare to the same extent as confinement in later lactation. This could support the use of temporary confinement in crates as a means to address concerns for sow welfare whilst reducing piglet mortality relative to non-crated systems (Moustsen et al., 2013).

It has been suggested that where stereotypies occur for more than 10% of the time an animal’s welfare is compromised (Broom, 1983; Broom, 1991). A recognised stereotypy that can manifest in intensively housed sows is bar-biting (Terlouw et al., 1991). The present results have shown the amount of time sows in crates and pens spent biting pen/crate fixtures was well below the level at which reduced welfare may be indicated as suggested by Broom (1983; 1991). However vacuum chewing, another behavioural stereotypy, increased in both systems over the observation period. Vacuum chewing was displayed less than 10% of the time during days 1, 2 and 3 in pens, but exceeded 10% of the time from day 4 in pens and from day 2 in crates. This is most likely attributed to the lack of manipulable material in both systems.

Given the opportunity to do so, pigs are strongly motivated to explore their environment (Studnitz et al., 2007). In the absence of a substrate, sows may direct exploratory behaviours towards pen or crate fittings (Studnitz et al., 2007), as was observed in this study once sows were loose in pens. These sows rooted at the floor more when loose compared to when they had been confined. This behaviour peaked on day 5 in pens, the day after being let loose from the temporary crate. Exploratory behaviour can be motivated by curiosity which may arise when the surroundings change (Wood-Gush and Vestergaard, 1989), as was the case once sows were released from their temporary crate.

Rooting and nosing activities enable exploration, but can also form part of the sequence described as pre-lying behaviour which is evident when rooting and nosing is performed immediately before lying down. Clough and Baxter (1984) found that rooting and nosing were performed before 88% of lying down events. These behaviours, in addition to piglet-directed behaviours such as vocalisation, may be carried out to ensure that piglets are awake and alert before a sow changes posture. Loose housed sows with no crushing-related piglet deaths performed more rooting behaviour on day three post-farrowing than sows which were found to have crushed piglets (Valros et al., 2003). In another study, sows which had not crushed any piglets performed significantly more sniffing during a pre-lying sequence than sows which had crushed piglets (Wischner et al., 2010). Nosing and "looking around" behaviour was performed more frequently in non-crushing sows. The present study recorded sows as investigating piglets when they turned towards, looked at and/or sniffed their piglets. This is similar to the "looking around" behaviour described by Wischner et al. (2010). Sows in pens investigated their piglets more than sows in crates, and this behaviour increased once they were loose. This may be demonstrative of an adaptation in response to increased piglet proximity, given that over time piglets in both systems were more active in the open area where the sow was located, and without the restriction of the crate, sows in pens could interact more with their piglets.

A sow maintains social contact with her litter through sniffing, grunting, nose contact and deliberately seeking out piglets (Blackshaw and Hagelsø, 1990). On day 1 post-farrowing, piglets in pens were more active in open areas than piglets in crates, and sows in pens investigated and touched their piglets more than sows in crates on the same day. Once loose, piglet-directed behaviours increased relative to when sows had been confined. Thus sows in pens interacted more with their piglets. Sows which exhibit high levels of activity may be more responsive towards piglets and more reactive to piglet distress calls (Thodberg, 2001). High levels of responsiveness and reactivity could be especially beneficial in non-crated farrowing and lactation systems. Through increasing the opportunities for sow and piglet interactions during lactation, behavioural development of piglets may be affected. Piglets reared by loose-housed sows showed less belly nosing and manipulative behaviour post-weaning. These piglets spent more time chewing, exploring feed, and playing post-weaning than piglets reared by confined sows (Oostindjer et al., 2011). Thus the rearing environment of piglets can affect their behavioural development and positively influence their behaviour post-weaning.

Observations of piglets

Piglet behaviour develops over the first week as they establish a routine of feeding, resting and periods of activity. The amount of time piglets spent in the creep area did not differ between the two systems during days 1 – 6 post-farrowing. Encouraging piglets away from the sow when they are not sucking is a difficult task. Attempts to make the creep more attractive to piglets to encourage them to use it more have been largely unsuccessful (Vasdal et al., 2010). Greater use of the creep was expected to improve piglet survival; however, there is no evidence that this is the case (Berg et al., 2006; Vasdal et al., 2009; Vasdal et al., 2010).

The behaviour and activities of sows and piglets in farrowing crates has been previously reported (Van Beirendonck et al., 2014). It was found that piglets were more likely to be observed running when sows were standing compared to when sows were lying. Thus piglets are more active (e.g. walking and running) when sows were also active e.g. rooting, eating and drinking (Van Beirendonck et al., 2014). A similar observation was made in the present study. Over time, piglets in both systems spent less time inactive at the sow's udder, whilst active behaviour in open areas increased. Sows in both systems were observed to stand more over time, consequently reducing the time spent lying, thus reducing the opportunities for piglets to be inactive at the udder. .

Sow activity could have been a predisposing factor related to the significantly higher pre-weaning piglet mortality that was recorded in these pens (10.2 %) compared to the crates (6.1 %) during this investigation (Chidgey et al., 2015). The timing of piglet deaths was influenced by whether the sow was loose or confined. A greater proportion of the piglets that died in pens were over the age of 4 days (38.8%) compared to those which died in crates (30.4%). Thus once sows in pens were loose and therefore more active, piglet mortality was higher in pens than in crates during the same interval. Higher pre-weaning piglet mortality in pens vs. crates has been reported previously (Cronin and Smith, 1992; Blackshaw et al., 1994; Marchant et al., 2000; Hales et al., 2014). The risk of crushing increases as more piglets spend time in close proximity to the sow (Weary et al., 1996b). These findings illustrate the conflict between a piglet's preference to stay close to the sow, and the subsequent risk that this carries with regard to accidental crushing by the sow.

It is unclear whether the sow influences the behaviour of the piglets, or the piglets influence the behaviour of the sow, or both. As piglet activity within open areas increased during days 1 – 6 post-farrowing, this may have influenced the behaviour of sows in pens once they were loose. These sows performed more piglet-directed behaviour during days 4 – 6 post-farrowing compared to when they had been confined. These interactions between sows and piglets serve to enhance the mother-young relationship, allowing piglets to convey their needs to the sow (Nowicki et al., 2012) whilst reinforcing mother-young olfactory and auditory recognition (Illmann et al., 2002; Kittawornrat and Zimmerman, 2011). In crates, interactions between sows and piglets are somewhat opportunistic, usually relying on the piglet to approach the head of the sow to initiate naso-naso contact. Piglet-directed behaviour by sows in crates did not change from day 2 post-farrowing, thus affirming the limited ability of sows in crates to interact with their piglets.

Conclusion

The motivation for developing alternative housing for sows during farrowing and lactation is based on improving their welfare. In this study, sows spent the majority of their time lying regardless of the farrowing system in which they were housed. However, once given the opportunity sows in pens were more active and as a result these sows expressed a greater repertoire of behaviour compared to sows in crates. Sow-piglet interactions were enhanced during lactation through limiting the confinement in crates to a maximum of 4 days post-farrowing. This likely served to further reinforce a more reciprocal relationship between sows and piglets in pens compared to those housed in crates.

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Chapter 5

The performance and behaviour of gilts and their piglets is influenced by whether they were born and reared in farrowing crates or farrowing pens.

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Abstract

The level of maternal care experienced by female offspring in early life may influence their future behaviour. If maternal behaviour is influenced by the level of mother-young interaction in early life, this may persist in subsequent generations through altered maternal behaviour of female offspring. In the present study, post-farrowing behaviour of gilts and their piglets was observed in a crossover experiment. Gilts were born and reared in a farrowing crate (C) or in a pen with temporary confinement (P); and were observed after they farrowed in a crate or a pen with temporary confinement. Hence there were four experimental groups (CC, CP, PC and PP). Gilts and their piglets were observed for the first three days post-farrowing whilst they were all confined in crates. There were no differences between groups for total born, born alive, weaned per litter, or piglet mortality. Gilts in the PP group interacted more with neighbouring sows than any other ($P < 0.05$). Gilts born and reared in pens touched their piglets more ($P_{born} = 0.02$) and vocalised more towards their piglets ($P_{born} = 0.01$) than gilts born and reared in farrowing crates. Piglets born to PP gilts spent more time active in the creep area compared to all other groups ($P < 0.05$). The current study demonstrated that the performance of some piglet-directed behaviour was influenced by the system in which a gilt was born and reared.

Keywords: Gilt behaviour; piglet behaviour; behaviour transmission; farrowing crates; farrowing pens.

Introduction

Future behaviour can be influenced by prenatal programming as well as the postnatal environment. In pigs, gilts born to sows which were mixed during pregnancy to induce stress expressed more abnormal maternal behaviours compared to daughters of control non-stressed sows (Jarvis et al., 2006). These daughters of stressed sows were more restless at parturition, more reactive to their piglets, and exhibited a greater tendency towards biting at their piglets compared to the daughters of control sows (Jarvis et al., 2006). This difference in maternal behaviour caused by prenatal programming of the first generation may shape the behaviour of the next generation.

The early experiences of neonatal mammals can have a long term effect on their future behaviour (Romeo et al., 2009). These experiences are influenced by mother-young interactions. The future maternal behaviour of a young female can be influenced by the quality and/or quantity of maternal care she experienced during the early stage of life (Fleming et al., 1999; Weaver et al., 2004; Champagne et al., 2011).

The transmission of maternal characteristics from one generation to the next has been investigated in rats (Francis et al., 1999; Francis and Meaney, 1999). Maternal lines were categorised by the amount of licking and grooming (LG) of their pups. As adults, females reared by high LG dams also showed higher frequencies of these behaviours towards their own offspring than those reared by low LG dams (Champagne et al., 2003; Francis et al., 1999a). Cross fostering at birth reversed these effects. Thus these differences in behaviour are influenced by maternal care received and these maternal characteristics are transmitted behaviourally (Francis et al., 1999; Francis and Meaney, 1999; Champagne et al., 2011).

In rats, maternal care affects the stress response of offspring (Francis and Meaney, 1999; Weaver et al., 2004). Adult offspring of high LG mothers were less fearful and exhibited a more moderate HPA response to stress than offspring of low LG mothers (Liu et al., 1997). Offspring of high and low LG mothers showed different behavioural responses to novelty (Caldji et al., 1998). Adult offspring of low LG dams showed increased startle responses, decreased exploration and a longer latency to eat food provided in a novel environment. This suggests that stress responsivity and social behaviour can be transmitted behaviourally (Champagne & Curley, 2005).

In a previous study by the same authors, sows that gave birth and nursed their piglets in different farrowing systems showed differences in maternal behaviour (Chidgey et al., 2016). Sows were housed in crates from 3 days pre-farrowing until day 4 of lactation. After this period they were loose within a pen until weaning at 28 days. Once loose, these sows vocalised towards piglets more than sows housed in farrowing crates from 5 days pre- until 28 days post-farrowing. Sows in pens performed more piglet-directed behaviour than sows in crates, thus mother-young interactions were enhanced in pens compared to farrowing crates (Chidgey et al., 2016).

The present study investigated the post-farrowing behaviours of gilts born to sows housed in pens (P) or crates (C). These gilts and their piglets were observed in a crossover experiment. The objective was to determine whether a gilt's exposure to different levels of maternal interaction in early life would influence their future maternal behaviour. Gilts were born and reared in either a farrowing crate (C) or a pen with temporary confinement (P); and were observed after they farrowed in a crate or a pen with temporary confinement, thus creating four treatment groups (CC, CP, PC, PP). Observations of gilts and their piglets were recorded for all four groups for the first three days post-farrowing whilst all gilts were still confined in crates.

Materials and methods

Animals and management

This study was carried out at a 1250 sow commercial pig farm in New Zealand with the approval of the Massey University Animal Ethics Committee (protocol 12/36). Gilt breeds were Large White, Landrace, Duroc, and Large White/Landrace cross. Breed distribution was random within the two farrowing systems. The farm which served as the location of the study operated a nucleus breeding herd. Hence all animals were born and reared on the same farm, and the female replacements were all subject to the same selection criteria in terms of the genetic traits that comprise the breeding herd. All gilts were naturally mated and housed indoors in groups of 10 for the duration of pregnancy. Four treatment groups of gilts were identified based on their birth and rearing system (pen or crate) and the system in which they were randomly allocated to farrow (pen or crate). Performance data was obtained from 192 gilts and 2192 piglets (total born) across the four treatment groups (number of gilts per group: CC = 72, CP = 44, PC = 51, PP = 25, Table 2). This included total born (the number of live born and stillborn piglets per sow as recorded within 12 hours of the end of farrowing), lactation length (the duration of lactation/ weaning age of piglets), and piglet mortality (the percentage of live born piglets that died before weaning). Observations were carried out on 27 gilts across the four treatment groups identified (CC = 8, CP = 6, PC = 5, PP = 8). Post-farrowing observations of gilts and piglets were recorded from day 1 to day 3 of lactation, whilst all gilts were confined in crates. Gilts were not observed during the day of farrowing (day 0). One observer recorded all of the behavioural observations throughout the study. Gilts and their piglets were not observed while staff performed husbandry tasks (piglet processing, vaccinations, fostering, and miscellaneous treatments). Piglet processing took place ~24 h after birth. This included teeth clipping, tail docking, recording total litter weight, administering an iron injection, and ear tagging. Piglets were cross-fostered within-system in the first 48 hours post-farrowing to equalise litter sizes at 11 – 12 piglets.

Gilts were moved into the farrowing accommodation 5 days before the estimated parturition date (date of first mating + 115 days). Those in farrowing crates were confined from 5 days before estimated parturition date until weaning (approximately 28 days after farrowing). Gilts in the farrowing pens were loose for the first two days and then confined in a crate, from day 3 before parturition until day 4 of lactation. The length of confinement pre-farrowing was decided by farm management based on their preference for operating the two systems. Stockpersons were present in the farrowing rooms each day from 0730 h to 1600 h to supervise farrowing.

On-farm farrowing accommodation included 30 farrowing pens and 256 farrowing crates. The farrowing pens were manufactured by Vissing Agro of Denmark (Combi-

Flex turn around farrowing pen); they measured 2.25 x 2.6m (5.85m^2 including creep area of 0.84m^2) and were fitted with an internal farrowing crate (2.1m in length, adjustable width) that was temporarily used to confine sows pre-farrowing and in early lactation. The feed trough was located in one corner of the pen next to a bowl drinker that was accessible to the sow and piglets. The covered triangular creep had a heated plastic floor pad that was set at 32°C at farrowing and reduced by 2 ºC each week until weaning. The creep had LED lights to attract piglets inside.

The farrowing crates were manufactured by Big Dutchman®. Crate width was adjustable to accommodate variable sow size, and crate length was fixed at 2.0m. The entire farrowing space (crate + creep and piglet areas) was approximately 3.84m^2 (1.6m x 2.4m). Each crate had a heated plastic floor pad for piglets which was set at 32°C at farrowing, and dropped 2 ºC each week until weaning. Infrared lamps were suspended over the creep area to provide supplementary heating for the first 5 days post-farrowing in crates. Both farrowing systems had fully slatted flooring. Farrowing room temperatures for both systems averaged 25ºC in winter and 20ºC in summer during the first week post-farrowing. Both systems had fan-assisted ventilation.

In both systems, a lactation diet was fed three times daily via a computer controlled liquid feeding system. The energy level of the lactation diet was 14.95 MJ DE/kg at 16.67% crude protein. Creep meal was provided for piglets from 7 days of age. Weaning occurred at approximately 28 days of age.

Observations of gilts and piglets

The variables chosen for observation of gilts and piglets were based on a review of the literature (Arey and Sancha, 1996; Cronin et al., 1996). The day of farrowing was day 0. Post-farrowing observations were recorded for days 1, 2, and 3. Gilts were fed at 0900 h and 1500 h. No observations were recorded from 15 minutes before to 20 minutes after feeding. Observations began after habituation to the observer for a period of 10 minutes. Gilts and piglets were observed during four periods throughout each day: AM1 (0800 h – 0845 h), AM2 (0920 h – 1100 h), PM1 (1230 h – 1445 h) and PM2 (1520 h – 1600 h). Gilt and piglet observations (Table 5.1) were sampled using fixed interval scan sampling. Each day 100 observations lasting 30-seconds each were recorded for a maximum of four gilts and their litters per farrowing system. During each 30 second period, gilt and piglet behaviour, piglet location and gilt posture were recorded. Therefore, during one 30 second period all of the variables that occurred during that time were recorded as they were not mutually exclusive. As more than one behavioural variable may occur within one sampling period, the total % of behaviours observed for gilts and piglets can add to more than 100. At each sampling period, the behaviour and location of all piglets in each litter was documented. Each gilt and litter were observed 30 seconds immediately after the previous litter, thus every two minutes a full rotation of four gilts was completed. Gilts were observed in the same sequence within one system.

Table 5.1. Parameters recorded during observations of gilts and piglets.

Parameter	Description
General gilt behaviour	
Eating	Lowering head into the feeder and ingesting food.
Drinking	Drinking water
Vacuum chewing	Repetitive chewing without food in the mouth
Grunt	Gilt vocalises
Alarm call	Gilt vocalises: alarm/ warning 'bark'
Nursing	Milk let-down, gilt is lying laterally and piglets are suckling.
Piglet-directed behaviour by gilts	
Investigate piglet/s	Gilt turns to and sniffs/ looks at piglet/s
Vocalise at piglet/s	Grunting at piglet (excludes nursing)
Touch Piglet/s	Gilt intentionally touches piglet i.e. with the nose
Nursing vocalisations	Low-pitched rhythmic signal for piglets to suckle; vocal response to udder stimulation by piglets
Gilt posture and posture changes	
Standing	Maintaining an upright body position with 4 legs supporting sow body weight
Sitting	Partly erect on front legs with the hindquarters in contact with the floor
Ventral lying	Lying on sternum/belly, udder is partially or totally obscured
Lateral lying	Lying flat on one side with a shoulder on the floor and udder exposed
Descending movements (1)	Gilt lays down from standing position
Descending movements (2)	Gilt lays down from a sitting position
Ascending movements	Gilt sits up from lying down, stands from lying, or stands from sitting position
Gilt location in pen	
Against wall/ surface	Gilt is lying against a wall or surface
Free of wall/surface	Gilt is lying in the middle of the pen without touching a wall/surface
Pen / crate directed behaviour by gilts	
Pawing	Gilt scrapes at floor with front leg/s
Rooting floor	Touching the floor with the snout ('digging'), accompanied by head movement
Biting fixture	Biting at any of the fixtures within the crate or pen (e.g. bars, trough)
Nosing fixture	Nasal contact, 'rubbing' fixtures of the pen/crate
Social behaviour towards other gilts/sows	
Alert	Turn towards, lifting head towards another gilt/sow
Investigate	Approaches another sow with interest, touches another sow, changes posture to view another gilt or sow
Vocalise	Grunts at another gilt/sow (non aggressive)
Agonistic	Aggressive/retaliatory behaviour towards other gilts/sows (e.g. bite, vocal 'bark')
Piglet location	
Udder (active/inactive)	Piglet is at the udder (sleeping or lying = inactive; teat seeking, massaging = active)
Adjacent	Piglet is within 0.1m of the sow, not at the udder or in the creep
Creep (active/inactive)	Piglet is in the creep area (sleeping/ lying = inactive; standing/sitting/walk = active)
Underneath	Piglet is under the sow when sow is standing
Open (active/inactive)	Not in the above locations ((sleeping/ lying = inactive; standing/sitting/walk = active)
Piglet behaviour	
Massage	Piglet is massaging the udder
Sucking	Piglet is suckling from a teat
Drinking	Drinking water, not suckling
Vocalising at sow	Piglet vocalising at the gilt (not while suckling)
Vocalising at littermate/s	Grunting at a fellow littermate while in close proximity and/or with eye contact
Agonistic	Piglet attacks (incl. biting and tail biting), and/ or retaliates to an attack
Chewing gilt	Piglet bites/chews the gilt (not while suckling)

All observations were documented on recording sheets in real time, or recorded on video cameras. The two farrowing systems (crates and pens) were in different rooms. If an overlap occurred due to gilts in different treatment groups farrowing within 6 days of one another, video cameras continuously recorded up to 4 gilts in one room/system throughout the day. The video footage was then reviewed by the same observer and scan sampled at the same interval as the real time observations. Data were identified by source (real time or video).

Gilt observations were described in the following categories (Table 5.1):

- General behaviour
- Piglet-directed behaviour
- Posture
- Pen/crate-directed behaviour
- Sow-directed behaviour

Piglet observations were described in the following categories (Table 5.1):

- Piglet location
- General piglet behaviour

Piglet behaviour was categorised as ‘inactive’ or ‘active’ in an effort to quantify their activity level. Play behaviour was incorporated within ‘active’ displays without specifically defining it as playing. Incidences of piglet vocalisations could be difficult to ascertain, especially as piglets were recorded as vocalising towards the gilt, or towards another littermate. These behaviours were distinguished through observing other factors i.e. if a piglet was vocalising whilst looking at, or turning towards another littermate, this was recorded as “vocalising towards a littermate”. Likewise, if there was reciprocal communication between piglets, it was clearer that the vocalisations were directed towards another piglet. Piglets vocalising towards the gilt was more obvious, as when the gilt is crated the piglet usually has to approach the head of the gilt in order to interact, thus piglets vocalising towards he gilts was a more deliberate action that was clearer to observe.

Behaviours of gilts directed towards neighbouring sows and/or gilts was the combination of four activities (alert, investigate, vocalise and agonistic). Though gilts were housed separately, interactions between neighbours were not completely prevented. If the observer was present during an overlying or a potential or actual injury event, intervention occurred in an attempt to save the piglet. This decision was made as the study took place on a commercial farm where normal staff protocol would be to intervene in this circumstance.

Statistical analysis

Performance data was extracted from the herd recording system EliteHerd® (Skorupski, 2003). In total, data was collected from 192 litters across the four treatment groups. The following variables were analysed: total born per litter, total born alive per litter, number weaned, total weaning weight of litter, lactation length, piglet weaning weight, gestation length and age of gilt at conception. This was performed using a linear model (PROC GLM) in SAS 9.2. Piglet mortality data (overall mortality) was analysed with a logit model (PROC GENMOD) in SAS 9.2. The fixed effects of ‘birth and rearing system', 'farrowing system', and an interaction between birth and rearing and farrowing system were included in the analysis of performance data and piglet mortality data. 'Lactation length' was included as a covariate for piglet average daily gain (ADG) to weaning.

Observations were recorded during a total of 8,100 individual time periods, (27 gilts and litters x 3 observation days x 100 30 – second observation periods) with 41 different behaviours (Table 5.1) recorded at each time period for gilts and piglets combined during the study. Binomial gilt behaviour was analysed after a logit transformation (PROC GENMOD) performed in SAS 9.2. The logit Lsmeans were back-transformed to calculate the % of scans during which each parameter was observed. The model included the fixed effects of 'day of observation' (day 1 – 3) 'birth and rearing system' and 'farrowing system' along with the interaction between the birth and rearing and farrowing system of the gilt. 'Gilt' was included as a random effect. Piglet behaviour data was calculated as the percentage of piglets within the litter displaying each behavioural parameter at a given time point. Piglet data was then analysed with PROC GENMOD with the fixed effects of 'day of observation' 'birth and rearing system' 'farrowing system' and the interaction between the birth and rearing and farrowing system of the gilt. 'Gilt' was included as a random effect. The logit Lsmeans were back-transformed to calculate the % of scans during which each parameter was observed. There was no interaction between the three main effects (day of observation, birth and rearing system, and farrowing system) for any of the gilt and piglet observation parameters. Therefore only the interaction between the 'birth and rearing system' and the 'farrowing system' is presented.

Results

Performance

There were no differences between groups for total born, born alive, pigs weaned per litter, and piglet mortality. Gestation length did not differ between treatment groups (Table 5.2, $P = 0.87$). Piglet average daily gain (ADG) was lowest in PP piglets but did not differ between CC, CP and PC piglets. Therefore litter weaning weight ($P < 0.01$) and piglet weaning weight (Table 5.2, $P < 0.01$) were lowest in the PP group, but did not differ between the other treatments. The system in which a gilt farrowed ~~was~~ had a significant effect ~~for~~ on litter weaning weight ($P_{farrow} = 0.01$). The system in which a gilt had been born and reared had a significant effect on lactation length ($P_{born} < 0.01$, Table 5.2) whereby gilts born and reared in pens with temporary crating (PP and PC) had a shorter lactation length than gilts born and reared in farrowing crates (CC and CP).

Table 5.2. A comparison of litter performance parameters between gilts that were born and reared in pens or crates and farrowed in pens or crates (Lsmean ± SE).

Performance parameter	Group[1]				P (LactLength)	P (Born)	P (Farrow)	P (Born x Farrow)
	CC	CP	PC	PP				
N litters	72	44	51	25				
Gestation length	114.5 (± 0.19)	114.6 (± 0.24)	114.8 (± 0.22)	114.8 (± 0.32)		0.24	0.75	0.87
Total Born	11.3 (± 0.36)	11.12 (± 0.47)	11.6 (± 0.43)	11.8 (± 0.62)		0.33	0.96	0.72
Born alive	10.9 (± 0.10)	10.9 (± 0.13)	11.2 (± 0.12)	10.9 (± 0.17)		0.31	0.33	0.16
Weaned	10.7 (± 0.35)	10.5 (± 0.45)	10.8 (± 0.42)	10.9 (± 0.59)		0.54	0.95	0.66
Piglet mortality[2]	-2.40 (± 0.13)	-2.08 (± 0.15)	-2.03 (± 0.13)	-1.99 (± 0.18)				
Piglet mortality (%)[3]	8.3%	11.1%	11.6%	12.4%		0.12	0.24	0.35
Litter weaning weight (kg)	89.1[a] (± 1.11)	89.6[a] (± 1.41)	91.3[a] (± 1.31)	82.1[b] (± 1.84)		0.20	0.01	<0.01
Piglet weaning weight (kg)	8.2[b] (± 0.07)	8.2[b] (± 0.09)	8.2[b] (± 0.08)	7.7[a] (± 0.11)		<0.01	0.01	<0.01
Piglet ADG (kg/day)	0.232[b] (± 0.003)	0.234[b] (± 0.004)	0.238[b] (± 0.003)	0.220[a] (± 0.005)	<0.01	0.29	<0.01	0.01
Lactation length (days)	29.4[b] (±0.31)	29.4[b] (± 0.40)	28.0[a] (± 0.37)	27.9[a] (± 0.52)		<0.01	0.91	0.98

[1]CC = born and reared in a crate, farrowed in a crate, CP = born and reared in a crate, farrowed in a pen, PC = born and reared in a pen, farrowed in a crate, PP = born and reared in a pen, farrowed in a pen.
[2]Logit estimate ± SE
[3]Back transformed %
[a,b]Values with different superscript differ significantly ($P < 0.05$)

Gilt behaviour and posture during the first three days post-farrowing

The amount of time spent lying, rooting, biting at fixtures, investigating piglets and performing nursing vocalisations did not differ between groups (Table 5.3). Gilts in CC and PP groups spent more time sitting than CP gilts, with PC in between (Table 5.3, $P = 0.04$). There was more vacuum chewing in CC and PP gilts than CP and PC gilts (Table 5.3, $P = 0.01$).

Table 5.3. Observations of gilt behaviour and posture during the first three days post-farrowing, Logit least square means ± SE (back transformed %)

Gilt Behaviour	Day 1 - 3 Logit Lsmean ± SE (back transformed %)				P (Day)	P (Born)	P (Farrow)	P (Born x Farrow)
	CC[1]	CP[1]	PC[1]	PP[1]				
Standing	-3.24 ±0.51 (3.8%)	-2.70 ±0.35 (6.3%)	-2.97 ±0.34 (4.9%)	-1.58 ±0.36 (17.1%)	0.38	0.11	0.04	0.34
Sitting	-3.39 ±0.42^{a} (3.3%)	-4.56 ±0.31^{b} (1.0%)	-3.79 ±0.43^{ab} (2.2%)	-3.28 ±0.22^{a} (3.6%)	0.18	0.27	0.40	0.04
Lying	2.84 ±0.54 (94.5%)	2.74 ±0.33 (93.9%)	2.69 ±0.37 (93.6%)	1.52 ±0.37 (81.0%)	0.19	0.13	0.13	0.26
Vacuum chewing	-2.87 ±0.33^{a} (5.4%)	-3.94 ±0.26^{b} (1.9%)	-3.88 ±0.24^{b} (2.0%)	-2.64 ±0.40^{a} (6.7%)	0.64	0.65	0.78	0.01
Rooting	-4.14 ± 0.55 (1.6%)	-4.08 ±0.37 (1.8%)	-4.34 ±0.43 (1.3%)	-3.60 ±0.33 (2.7%)	0.16	0.80	0.32	0.50
Bite	-5.71 ±0.53 (0.3%)	-6.12 ±0.29 (0.2%)	-5.71 ±0.28 (0.3%)	-4.32 ±0.43 (1.3%)	0.50	0.06	0.21	0.12
Nose	-4.90 ±0.39 (0.7%)	-3.80 ±0.29 (2.2%)	-4.27 ±0.41 (1.4%)	-3.23 ±0.35 (3.8%)	0.25	0.16	0.02	0.94
Paw	-7.86 ±0.97 (0.04%)	-5.77 ±0.33 (0.3%)	-7.39 ±0.90 (0.1%)	-4.90 ±0.44 (0.7%)	0.45	0.45	0.01	0.79
Sow-directed	-4.14 ±0.26^{b} (1.6%)	-4.02 ±0.34^{b} (1.8%)	-4.81 ±0.57^{b} (0.8%)	-2.98 ±0.37^{a} (4.8%)	0.11	0.67	0.04	0.04
Vocalise at piglet	-2.40 ±0.16 (8.3%)	-2.61 ±0.15 (6.8%)	-2.21 ±0.18 (9.9%)	-1.70 ±0.21 (15.4%)	0.09	0.01	0.41	0.06
Investigate piglet	-2.38 ±0.24 (8.5%)	-2.42 ±0.24 (8.2%)	-2.14 ±0.19 (10.5%)	-1.83 ±0.19 (13.8%)	0.15	0.08	0.54	0.43
Touch piglet	-2.75 ± 0.17 (6.0%)	-3.06 ±0.27 (4.5%)	-2.48 ±0.19 (7.7%)	-2.27 ±0.15 (9.4%)	0.12	0.02	0.82	0.20
Nurse	-4.10 ±0.21^{b} (1.6%)	-3.76 ±0.10^{ab} (2.3%)	-3.60 ±0.10^{a} (2.7%)	-3.90 ±0.09^{b} (2.0%)	0.79	0.14	0.79	0.03
Nursing vocalisation	-2.92 ±0.10 (5.1%)	-2.89 ±0.14 (5.3%)	-2.52 ±0.15 (7.5%)	-2.91 ±0.08 (5.1%)	0.06	0.14	0.16	0.11

[1]CC = born and reared in a crate, farrowed in a crate, CP = born and reared in a crate, farrowed in a pen, PC = born and reared in a pen, farrowed in a crate, PP = born and reared in a pen, farrowed in a pen.
[a,b]Values with different superscript differ significantly ($P < 0.05$)

More sow-directed behaviour was performed by gilts in the PP group than any other ($P = 0.04$). This behaviour was rarely observed (less than 2% of the time) in CC, CP and PC gilts. Gilts in the PC group nursed their piglets more often than CC and PP gilts during the first three days post-farrowing (Table 5.3, $P = 0.03$); however there was no difference in nursing behaviour between CP and PC gilts.

The system in which a gilt was born and reared had a significant effect on piglet-directed behaviour. Gilts born and reared in pens touched their piglets more ($P_{born} = 0.02$) and vocalised more towards their piglets ($P_{born} = 0.01$) than gilts born and reared in farrowing crates (Table 5.3). The system in which a gilt farrowed had a significant effect on the time spent standing; gilts that farrowed in crates within a pen (i.e. PP, CP) stood more than those that farrowed in a farrowing crate (i.e. CC, PC) (Table 5.3, $P_{farrow} = 0.04$). Nosing ($P_{farrow} = 0.02$), pawing ($P_{farrow} = 0.01$), and sow-directed behaviour ($P_{farrow} = 0.04$) were performed more often by gilts that farrowed in crates within a pen (PP, CP) than by gilts which farrowed in crates (CC, PC).

Piglet behaviour and location during the first three days post-farrowing

Vocalisations by piglets towards their littermates and towards their dam did not differ between groups (Table 5.4). Vocalisations by piglets were observed at a very low frequency throughout the study in all groups (up to 2% of observations). Vocalisations towards littermates tended to decrease over days 1 – 3 ($P_{day} = 0.03$, Table 5.4).

Table 5.4. Observations of piglet behaviour and location during the first three days post-farrowing, Logit least square means ± SE (back transformed %)

Piglet behaviour	Day 1 - 3 Logit Lsmean ± SE (back transformed %)				P (Day)	P (Born)	P (Farrow)	P (BornxFarrow)
	CC[1]	CP[1]	PC[1]	PP[1]				
Udder active	-1.57 ± 0.07^{b} (17.2%)	-1.11 ± 0.12^{a} (24.8%)	-1.08 ± 0.05^{a} (25.3%)	-1.46 ± 0.11^{b} (18.9%)	<0.01	0.45	0.61	<0.01
Udder inactive	-2.03 ±0.29 (11.6%)	-1.76 ±0.28 (14.7%)	-1.70±0.35 (15.5%)	-1.97 ±0.36 (12.3%)	<0.01	0.07	0.43	0.05
Creep active	-2.90 ± 0.11^{b} (5.2%)	-3.09 ± 0.15^{b} (4.4%)	-3.07 ± 0.07^{b} (4.4%)	-2.53 ± 0.14^{a} (7.4%)	0.55	0.13	0.19	0.01
Creep inactive	0.15 ± 0.17^{a} (53.7%)	-0.29 ± 0.18^{ab} (42.9%)	-0.51 ± 0.17^{b} (37.5%)	-0.05 ± 0.20^{ab} (48.7%)	<0.01	0.25	0.95	0.03
Open active	-2.68 ±0.14 (6.4%)	-2.83 ±0.12 (5.6%)	-2.59 ±0.10 (7.0%)	-2.66 ±0.13 (6.5%)	0.07	0.31	0.39	0.78
Open inactive	-3.25 ±0.27 (3.7%)	-3.49 ±0.38 (2.9%)	-3.17 ±0.34 (4.0%)	-4.76 ±0.31 (0.9%)	0.15	0.20	0.06	0.16
Massage	-1.89 ± 0.07^{b} (13.2%)	-1.34 ± 0.11^{a} (20.8%)	-1.40 ± 0.02^{a} (19.8%)	2.00 ± 0.11^{b} (11.9%)	0.17	0.32	0.77	<0.01
Sucking	-4.27 ± 0.22^{b} (1.4%)	-3.77 ± 0.11^{a} (2.3%)	-3.71 ± 0.10^{a} (2.4%)	-4.05 ± 0.08^{b} (1.7%)	0.87	0.31	0.57	0.01
Vocal sow	-5.76 ±0.17 (0.3%)	-6.02 ±0.22 (0.2%)	-5.39 ±0.50 (0.5%)	-4.53 ±0.24 (1.1%)	0.19	0.09	0.31	0.07
Vocal pig	-4.00 ±0.17 (1.8%)	-4.36 ±0.13 (1.3%)	-3.89 ±0.16 (2.0%)	-3.84 ±0.16 (2.1%)	0.03	0.07	0.35	0.23

[1]CC = born and reared in a crate, farrowed in a crate, CP = born and reared in a crate, farrowed in a pen, PC = born and reared in a pen, farrowed in a crate, PP = born and reared in a pen, farrowed in a pen.
[a,b]Values with different superscript differ significantly (*$P < 0.05$*)

Piglets in the CC and PP groups spent less time active at the udder than CP and PC piglets (Table 5.4, $P < 0.01$). There was also a significant main effect of the day of observation whereby active behaviour at the udder decreased over days 1 – 3 post-farrowing ($P_{day} < 0.01$). Inactive behaviour at the udder did not differ between groups. This behaviour also tended to decrease each day during the observation period ($P_{day} < 0.01$, Table 5.4). Thus over time, both active and inactive behaviour at the udder decreased in all treatments.

Piglets were observed as being active or inactive within open areas of the farrowing space, and there was no difference between groups for this parameter. Piglets in the CC, CP and PC groups did not differ in the amount of time they spent active in the creep area, whereas PP piglets spent more time active in the creep compared to the others (Table 5.4, $P = 0.01$). Inactive behaviour in the creep did not differ between CC, CP and PP groups but CC piglets spent more time inactive in the creep than those in the PC group (Table 5.4). Piglets tended to increase the time they spent inactive in the creep over days 1 – 3 post-farrowing (Table 5.4, $P_{day} < 0.01$).

Observations of udder massage activity did not differ between piglets in CC and PP groups (Table 5.4). These piglets spent less time massaging the udder than piglets in CP and PC groups ($P < 0.01$). This was also the case for observations of sucking activity, which did not differ between CC and PP groups however these piglets performed less of this activity than those in CP and PC groups ($P = 0.01$, Table 5.4).

Discussion

Early life experience is emerging as having a significant role in shaping and perpetuating behaviour across generations (Champagne et al., 2011). The quality and/or quantity of mother-young interactions can have a long term influence on offspring behaviour. Behavioural transmission of maternal behaviour from dam to daughter does occur (Champagne et al., 2008) and could persist in subsequent generations via altered behaviour of female offspring. The purpose of this study was to investigate whether the environment in which a gilt was born and reared could influence her future maternal behaviour. Our findings have shown that a gilt's birth and rearing system influenced the performance of some maternal characteristics that related to piglet-directed behaviour. More specifically, gilts born and reared in pens vocalised more towards, and touched their piglets more than gilts born and reared in farrowing crates.

It has been demonstrated in rats (Francis et al., 1999; Francis and Meaney, 1999; Champagne et al., 2003), monkeys (Maestripieri 2005), pigs (Oostindjer et al., 2011) dogs (Slabbert and Rasa, 1997), prairie vole (Perkeybile et al., 2015) and many other animals, that their young can learn how to behave through observing as opposed to imitating their mothers. A behavioural pattern is described as 'learned' when the effect of the observation remains for an extended period after the initial observational experience (Klopfer, 1961). Sows in pens performed more piglet-directed behaviour than sows in crates (Chidgey et al., 2016). Thus, piglets reared in these farrowing systems potentially experienced different levels of maternal care. In the present study, gilts born and reared in pens (PP and PC) vocalised towards and touched their own piglets more than gilts born and reared in farrowing crates (CC and CP). Adaptive maternal programming can influence offspring phenotype to prepare them in the event that they experience similar circumstances in later life (Groothuis and Taborsky, 2015). Hence, the environment these gilts experienced as piglets during early postnatal development may explain differences in their own maternal behaviour.

Throughout life, animals collect information and use it to adjust their developmental trajectories, including modifying their behaviour to suit particular situations and environments (Groothuis and Taborsky, 2015). In the context of sow behaviour, this may have implications for mothering ability. An example of this has been described in farrowing crates. Sows vary widely in their inherent reactivity to piglet distress calls (Illmann et al., 2008). The observed nonresponsiveness of some sows may be an adaptation to environmental conditions, given that sows in farrowing crates are housed in close proximity to other sows and their litters. In this environment sows are subjected to distress calls elicited by neighbouring piglets. Over time sows may learn not respond to these vocalisations, as sows which have previously reacted through changing their posture learn that it does not always stop the piglet from vocalising (Lay et al., 2002). The implication here is that if a nonresponsive sow eventually does trap one of her own piglets, she may not react. When a physical and social environment is perpetuated across generations, this can encourage multigenerational transmission of a particular phenotype (Szyf, 2015). Thus, this nonresponsiveness may be perpetuated in the next generation by adult daughters that later farrow in the same environment. The development of a behavioural trait in response to a specific production system may improve animal welfare if that trait assists adaption to that system (Knap, 2013). However, given that modern housing systems have a short history relative to the domestication of pigs, adaptation may not have caught up to the rate at which intensification has occurred (Kruska, 2005).

If the environment an individual experiences in later life differs from what was predicted, a mismatch may occur (Groothuis and Taborsky, 2015). This mismatch may compromise ‘fitness’ of the affected offspring. In the event that an early life experience has not adequately predicted a later environment, there needs to be a way to check the early prediction and adjust accordingly to suit the present environment. Hence, behavioural development continues in to adulthood, and is sensitive to environmental feedback. This also serves to reinforce accurately predicted information gathered during early development. Gilts by definition have not previously experienced parturition, therefore in each case it was their first experience in a farrowing environment. This in itself would have induced some degree of adaptation to these novel surroundings in all experimental animals. In the case of the two crossover groups (PC and CP), there is no clear conclusion as to whether there are indications of a mismatch or maladaptation to their farrowing environment. Interestingly, gilts in PC and CP groups performed significantly less vacuum chewing than CC and PP gilts. Behavioural stereotypies may indicate compromised welfare where they are observed more than 10% of the time (Broom, 1983; Broom, 1991). It should be noted that for all groups, observations of vacuum chewing behaviour ranged from 1.9% in CP gilts to 6.7% in PP gilts, below the level at which welfare may be compromised.

During days 1 – 3 post-farrowing all gilts spent most of their time lying down. Other studies reported that sows in farrowing pens were lying down approximately 90% of the time during the first three days post-farrowing (Hohenshell et al., 1996; Minnick et al., 1997). This inactivity is common in the first 24 – 48 hours after farrowing (Johnson & Marchant-Forde, 2009). Sow activity level is linked to piglet mortality whereby sows which spend more time lying are less likely to crush piglets compared to more active sows (Lay et al., 2002). Even though all gilts were confined in crates, there were still differences in their behaviour across the four treatment groups. PP gilts tended to be more active, as these gilts spent more time standing and performed more sow-directed behaviour than CC, CP and PC gilts. Most injuries to piglets are caused when sows change position i.e. from standing to lying (Svendsen et al., 1986; Wechsler and Hegglin, 1997). Though there was no statistically significant difference in piglet mortality between groups, piglet mortality was numerically higher in PP gilts (12.4%) compared to CC (8.3%), CP (11.1%) and PC (11.6%) gilts.

Piglet behaviour was mostly influenced by the day of observation. From a piglet's perspective it is critical that they adapt to their unfamiliar and unpredictable extra-uterine environment rapidly and successfully (Mellor and Lentle, 2015). This transitional period is marked by physiological and survival-critical behavioural adaptations (Mellor and Lentle, 2015). Failure to adapt has serious consequences, illustrated by the finding that approximately 70% of piglet mortality occurs in the first 3 days post-farrowing (Tuchscherer et al., 2000). During this time, a routine develops that consists of active, inactive and ingestive behaviour. Thus, throughout the first three days post-farrowing, piglets reduced the time they spent at the udder and increased the time they spent inactive in the creep area. A similar observation was made previously where piglets reduced the time they spent resting near the sow in pens and crates over the first 72 hours after birth (Vasdal et al., 2009).

There was no difference between groups for pre-weaning piglet mortality, as the number of observations in this study was too low to observe a statistically significant difference between treatments. This should be noted in the context of interpreting findings from studies where piglet mortality has been compared across different farrowing systems. Some studies have found that pre-weaning piglet mortality was higher in pens than in crates (Cronin and Smith, 1992; Blackshaw et al., 1994; Marchant-Forde et al., 2000; Hales et al., 2014). Others found no difference in piglet mortality between pens and crates (Cronin et al, 2000; Weber et al., 2007; KilBride et al., 2012). In order to detect a difference in mortality of 0.2 piglets per litter, data from at least 300 farrowings per treatment would need to be collected (Damm et al., 2005). However, there are very few commercially-based studies of sufficient sample size comparing piglet mortality between farrowing crates and pen-based alternatives. This makes it difficult to conclude which system is 'best' as commercial viability is a crucial factor in selecting a feasible alternative to farrowing crates.

Conclusion

Gilts reared in pens experienced a greater level of mother-young interaction as piglets compared to those reared in farrowing crates. When these gilts farrowed in later life, they vocalised towards and touched their own piglets more than those reared in farrowing crates. Hence, a gilt's maternal behaviour can be influenced by the level of maternal care experienced in early life. This may have implications for improving adaptation to a new housing system, thus benefitting animal welfare and performance.

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Chapter 6

Sow and piglet behavioural associations in farrowing pens with temporary crating or farrowing crates

Abstract

The farrowing system in which a sow and her piglets are housed may have an influence on the manner in which they interact with one another. The behavioural displays of sows in farrowing crates are limited, whereas pen-based alternatives to farrowing crates enable a greater range of behavioural expression, including interacting more with piglets. Thus the associations between sow behaviour and piglet behaviour in crates and pens with temporary crating were compared using two different data sets. During days 1 – 6 post-farrowing, 15 sows and their litters were observed in farrowing crates, and 16 sows and their litters were observed in pens with temporary crating. Sows in farrowing crates were crated throughout days 1 - 6, and sows in pens were crated during days 1 – 3 (Period 1) and loose in the pen on days 4 – 6 (Period 2). Additionally, gilts and their litters were observed during the first 3 days post-farrowing. Gilts were either born and reared in farrowing crates (C) or in a pen with temporary crating (P); and were observed after they farrowed in either a farrowing crate or in a pen with temporary crating. Hence there were four experimental groups: CC (born and reared in a crate, farrowed in a crate, $N = 8$), CP (born and reared in a crate, farrowed in a pen, $N = 6$), PC (born and reared in a pen, farrowed in a crate $N = 5$), and PP (born and reared in a pen, farrowed in a pen, $N = 8$). When sows and gilts were standing, piglets were mostly inactive in the creep area. When they were lying, piglets were inactive either in the creep, or at the sow's udder. Piglets in pens spent more time inactive at the sow's udder compared to piglets in crates when the sow was lying in period 1 and in period 2 when penned sows were loose ($P < 0.01$). Piglets tended to be active when sows and gilts touched, investigated and vocalised towards them. Piglets of gilts that were born and reared in pens and farrowed in pens (PP) vocalised more towards their dam than those in CC,CP

and PC groups, particularly when their dam was vocalising towards them ($P < 0.01$), investigating them ($P < 0.01$ and touching them ($P < 0.01$). The current study demonstrated that some associations between sow and piglet behaviour change when the sow is no longer confined in a crate. Furthermore, the piglets of gilts born and reared in a farrowing system that did not match the environment they later farrowed in may be influenced by their dam's adaptation to an unfamiliar environment.

Introduction

It is not always clear whether the sow influences the behaviour of the piglets or the piglets influence the behaviour of the sow, or both. Mother-young interactions are influenced by the environment, thus reciprocal exchanges between a sow and her offspring may be limited by the farrowing system in which they are housed (Schwabl and Groothuis, 2010). However it is likely that sows and piglets still influence one another's behaviour, even in a confined environment such as a farrowing crate where the sow's behavioural displays are limited. An obvious example of sows and piglets influencing one another relates to nursing behaviour, where piglets can communicate their hunger through massaging the sow's udder (Fraser et al., 1980; Jensen and Algers, 1984), and the sow can announce that it is time for the piglets to begin suckling through vocalising at a very specific pitch and frequency (Algers and Jensen, 1985). Nursing behaviour is a survival-critical behaviour (Mellor and Lentle, 2015) that does not show significant variation between farrowing systems (Fraser, 1980; Johnson et al., 2001). It is less clear how general behavioural displays of sows and piglets may be influenced by the farrowing system design. The association between the behaviour of sows and their piglets in a commercial setting has not been widely examined, though studies in farrowing crates showed that piglets preferred to rest when the sow was also resting, and when sows were standing piglets tended to be active (van Beirendonck et al., 2014). There has been no such investigation of the connection between sow behaviour and piglet behaviour in pen-based farrowing systems, or those which use temporary crating of sows early in lactation. Furthermore, the associations between sow and piglet interactions have not been studied. Such information could provide insight into the dynamics of sow and piglet behaviour in an alternative farrowing system, thus improving our understanding of their behavioural patterns in non-crated farrowing systems.

The objective of this study was to investigate the relationship between sow and gilt behaviour and posture, and piglet behaviour. These relationships were compared between farrowing crates and farrowing pens with temporary crating.

Materials and methods

Animals and management

This study was carried out at a 1250 sow commercial pig farm in New Zealand with the approval of the Massey University Animal Ethics Committee (protocol 12/36). Sow breeds were Large White, Landrace, Duroc, and their crosses, and sows ranged from parity 2 to 10. Sows were mixed into groups at weaning, bred by artificial insemination, and housed indoors in groups of 10 for the duration of pregnancy. All gilts were naturally mated and housed indoors in groups of 10 for the duration of pregnancy. In the first data set the sows were organised as ‘batches’ based on the 5-weekly cycle of the farrowing pens being emptied and reloaded. Observations were carried out on 31 randomly selected sows over 4 batches. All sows were familiar with farrowing crates only. Post-farrowing observations of sows and piglets were recorded from day 1 to day 6 of lactation. For details of this experiment see Chidgey et al. (2016a).

In the second data set, four treatment groups of gilts were identified based on their birth and rearing system (pen or crate) and the system in which they were randomly allocated to farrow (pen or crate). Observations were carried out on 27 gilts across the four treatment groups identified: (CC = 8, CP = 6, PC = 5, PP = 8). Post-farrowing observations of gilts and piglets were recorded from day 1 to day 3 of lactation, whilst all gilts were confined in crates. Further details of this experiment are reported in Chidgey et al. (2016b *submitted*).

Sows and gilts were not observed during the day of farrowing (day 0). One observer recorded all of the behavioural observations throughout the study. Sows and gilts and their piglets were not observed while staff performed husbandry tasks. These included piglet processing, vaccinations, fostering, and miscellaneous treatments.

Sows and gilts were moved into the farrowing accommodation 5 days before the estimated parturition date (date of first mating + 115 days). Those in farrowing crates were confined from 5 days before estimated parturition date until weaning (approximately 28 days after farrowing). Sows and gilts in the farrowing pens were loose for the first two days, and were then confined in a crate from day 3 before parturition until day 4 of lactation. The length of confinement pre-farrowing was decided by farm management. The decision to remove the temporary crates on day 4 was based on the knowledge that the majority of piglet deaths occur in the first three days post-farrowing. Thus confinement to day 4 would aid supervision and intervention at this critical period. In addition, most of the piglet husbandry tasks, including fostering, were completed by day 4 post-farrowing thus after this period, routine management was not impeded by the sow being loose.

Parturition was induced in sows only, approximately 113-114 days post-mating. A split dose of $PGF_{2\alpha}$ analogue EstroPLAN® (Parnell Laboratories Pty Ltd, equivalent to 250 µg cloprostenol/mL) was injected at the vulva-cutaneous junction. Stockpersons were present in the farrowing rooms each day from 0730 h to 1600 h to supervise farrowing.

Piglet processing took place ~24 h after birth. This included teeth clipping, tail docking, recording total litter weight, administering an iron injection, and ear tagging. Piglets were cross-fostered within-system in the first 48 hours post-farrowing to equalise litter sizes at 11 – 12 piglets per litter.

On-farm farrowing accommodation included 30 farrowing pens and 256 farrowing crates. Every 5 weeks, a batch of 56 sows was randomly allocated to farrow in either farrowing pens or farrowing crates. The farrowing pens were manufactured by Vissing Agro of Denmark (Combi-Flex turn around farrowing pen); they measured 2.25 x 2.6m ($5.85m^2$ including creep area of $0.84m^2$) and were fitted with an internal farrowing crate (2.1m in length, adjustable width) that was temporarily used to confine sows and gilts pre-farrowing and in early lactation. The feed trough was located in one corner of the pen next to a bowl drinker that was accessible to the sow and piglets. The covered triangular creep area had a heated plastic floor pad that was set at 32°C at farrowing and reduced by 2 ºC each week until weaning. The creep had LED lights to attract piglets inside.

The farrowing crates were manufactured by Big Dutchman®. Crate width was adjustable to accommodate variable sow size, and crate length was 2.0m. The entire farrowing space (crate + creep and piglet areas) was approximately 3.84m^2 (1.6m x 2.4m). Each crate had a heated plastic floor pad for piglets which was set at 32°C at farrowing, and dropped 2 ºC each week until weaning. Infrared lamps were fixed above the heated floor pad to provide supplementary heating for the first 5 days post-farrowing in crates. Both farrowing systems had fully slatted flooring. Farrowing room temperatures for both systems averaged 25ºC in winter and 20ºC in summer during the first week post-farrowing. Both systems had fan-assisted ventilation.

In both systems, lactating sows and gilts were fed three times daily via a computer controlled liquid feeding system. The energy level of the lactation diet was 14.95 MJ DE/kg at 16.67% crude protein. Creep meal was provided for piglets from 7 days of age. Weaning occurred at approximately 28 days of age.

Observations of sows and piglets

The day of farrowing was day 0. Post-farrowing observations of sows were recorded for days 1, 2, 3, 4, 5 and 6. Post-farrowing observations of gilts were recorded for days 1, 2 and 3. Sows and gilts were fed twice during observation hours at 0900 h and 1500 h. No observations were recorded from 15 minutes before to 20 minutes after feeding. Observations began at 0800 h after a habituation period of 10 minutes. Sows/gilts and piglets were observed during four sessions throughout each day: AM1 (0800 h – 0845 h), AM2 (0920 h – 1100 h), PM1 (1230 h – 1445 h) and PM2 (1520 h – 1600 h). On day 4 sows in pens were let out of their crates approximately one hour before AM1. This allowed sows to adjust to their altered surroundings before observations began. Sow/gilt and piglet observations (Table 6.1) were sampled using fixed interval scan sampling. Each day 100 observations lasting 30-seconds each were recorded for four sows and their litters per farrowing system. During each 30 second period, sow/gilt and piglet behaviour, piglet location and sow/gilt posture were recorded. Therefore during one 30 second period, all of the variables that occurred during that time were recorded as they were not mutually exclusive. At each sampling period, the behaviour and location of all piglets in each litter was documented. Each sow and litter were observed 30 seconds immediately after the previous litter, thus every two minutes a full rotation of four sows was completed. Sows and gilts were observed in the same sequence within one system.

All observations were documented either on recording sheets in real time, or recorded on video cameras. Sows and gilts in the two farrowing systems were housed in different rooms. If an overlap occurred due to sows in different systems farrowing within 6 days of one another, video cameras continuously recorded 4 sows in one room/system throughout the day. The video footage was then reviewed by the same observer and scan sampled at the same interval as the real time observations. Data were identified by source (real time or video). The variables chosen for observation were based on a review of the literature (Arey and Sancha, 1996; Cronin et al., 1996) and are described in the following categories (Table 6.1):

Table 6.1. Parameters recorded during observations of gilts and piglets.

Parameter	Description
General gilt behaviour	
Eating	Lowering head into the feeder and ingesting food.
Drinking	Drinking water
Vacuum chewing	Repetitive chewing without food in the mouth
Grunt	Gilt vocalises
Alarm call	Gilt vocalises: alarm/ warning 'bark'
Nursing	Milk let-down, gilt is lying laterally and piglets are suckling.
Piglet-directed behaviour by gilts	
Investigate piglet/s	Gilt turns towards and sniffs/ looks at piglet/s
Vocalise at piglet/s	Grunting at piglet (excludes nursing)
Touch Piglet/s	Gilt intentionally touches piglet, i.e. with the nose
Nursing vocalisations	Low-pitched rhythmic signal for piglets to suckle; vocal response to udder stimulation by piglets
Gilt posture and posture changes	
Standing	Maintaining an upright body position with 4 legs supporting sow body weight
Sitting	Partly erect on front legs with the hindquarters in contact with the floor
Ventral lying	Lying on sternum/belly, udder is partially or totally obscured
Lateral lying	Lying flat on one side with a shoulder on the floor and udder exposed
Descending movements (1)	Gilt lays down from standing position
Descending movements (2)	Gilt lays down from a sitting position
Ascending movements	Gilt sits up from lying down, stands from lying, or stands from sitting position
Gilt location in pen	
Against wall/ surface	Gilt is lying against a wall or surface
Free of wall/surface	Gilt is lying in the middle of the pen without touching a wall/surface
Pen / crate directed behaviour by gilts	
Pawing	Gilt scrapes at floor with front leg/s
Rooting floor	Touching the floor with the snout ('digging'), accompanied by head movement
Biting fixture	Biting at any of the fixtures within the crate or pen (e.g. bars, trough)
Nosing fixture	Nasal contact, rubbing fixtures of the pen/crate
Social behaviour towards other gilts/sows	
Alert	Turn towards, lifting head towards another gilt/sow, directs attention to a sow/gilt
Investigate	Approaches another sow with interest, touches another sow, changes posture to view another sow/gilt
Vocalise	Grunts at another sow/gilt (non aggressive)
Agonistic	Aggressive/retaliatory behaviour towards other sows (e.g. bite, vocal 'bark')
Piglet location	
Udder (active/inactive)	Piglet is at the udder (sleeping or lying = inactive; teat seeking, massaging = active)
Adjacent	Piglet is within 0.1m of the sow, not at the udder or in the creep
Creep (active/inactive)	Piglet is in the creep area (sleeping/ lying = inactive; standing/sitting/walk = active)
Underneath	Piglet is under the sow when sow is standing
Open (active/inactive)	Not in the above locations ((sleeping/ lying = inactive; standing/sitting/walk = active)
Piglet behaviour	
Massage	Piglet is massaging the udder
Sucking	Piglet is suckling from a teat
Drinking	Drinking water, not suckling
Vocalising at gilt	Piglet vocalising at the gilt (not while suckling)
Vocalising at littermate/s	Grunting at a fellow littermate while in close proximity and/or with eye contact
Agonistic	Piglet attacks (incl. biting and tail biting), and/ or retaliates to an attack
Chewing gilt	Piglet bites/chews the gilt (not while suckling)

Sow/gilt observations:

- General behaviour
- Piglet-directed behaviour
- Posture
- Pen/crate-directed behaviour
- Sow-directed behaviour

Piglet observations:

- Piglet location
- General piglet behaviour

Piglet behaviour was categorised as 'inactive' or 'active' in an effort to quantify their activity level. Play behaviour was incorporated within 'active' displays without specifically defining it as playing. If the observer was present during an overlying or a potential or actual injury event, intervention occurred in an attempt to save the piglet. This decision was made as the study took place on a commercial farm where normal staff protocol would be to intervene in this circumstance.

Statistical analysis

Sow and piglet behavioural associations were analysed using SAS 9.2. The relationship between sow behaviour and piglet behaviour was analysed with the GLM procedure. Sow and gilt behavioural data were binomial. These data were analysed after a logit transformation (PROC GENMOD) performed in SAS 9.2. The logit Lsmeans were then back-transformed to calculate the % scans during which each parameter was observed.

The model included the fixed effects of ‘farrowing system’, ‘period’, ‘sow behaviour’ and the interaction between all three. A random effect of ‘sow; was included, and ‘sow’ was used as a repeated subject in the model. Piglet behavioural data was calculated as the mean percentage of piglets displaying each behavioural parameter at a given time point. Correlations between sow behaviour and piglet behaviours were calculated in SAS 9.2 using the CORR procedure. Each correlation model analysed one sow behaviour parameter against all of the piglet behaviour parameters by ‘farrowing system’ and ‘period’. A 1-tailed Fisher’s r-to-z transformation was used to test the difference between correlation coefficients for sow/piglet behaviours, comparing period 1 (days 1, 2 and 3 post-farrowing) and period 2 (days 4, 5 and 6 post-farrowing) within system.

The relationship between gilt behaviour and piglet behaviour was analysed with the GLM procedure, using the mean (per litter per day) for each of the piglet behavioural parameters. The model included the fixed effects of ‘birth and rearing location’, ‘farrowing location’, ‘group’, ‘gilt behaviour’ and the interaction between the birth and rearing location, farrowing location, and gilt behaviour . The ‘group’ category describes the combination of the birth and rearing locations, e.g. ‘CC’ is born and reared in a crate farrowed in a crate; ‘PP’ is born and reared in a pen, farrowed in a pen; whereas CP and PC are the two crossover treatment groups. A random effect of ‘gilt’ was included, and ‘gilt’ was used as a repeated subject in the model. Correlations between gilt behaviour and piglet behaviours were calculated in SAS 9.2 using the CORR procedure. Each correlation model analysed one gilt behaviour parameter against all of the piglet behaviour parameters by ‘birth and rearing location’, ‘farrowing location’ and ‘group’.

A 1-tailed Fisher's r-to-z transformation was used to test the difference between correlation coefficients for gilt/piglet behaviours to compare the four groups.

Results

Observations of sows and their piglets in period 1 and period 2 post-farrowing

Observations of piglets while sows were standing and lying

Correlation coefficients are presented in Tables 6.2 and 6.5. Some significant correlations (and behavioural associations) considered obvious were not presented (i.e. sows/gilts nursing, and piglets sucking; sows/gilts performing nursing vocalisations and piglets massaging the udder).

Table 6.2. Differences between sow and piglet behaviour correlations in period 1 and period 2 in crates (N = 15) and pens (N = 16).

Sow Behaviour	Piglet Behaviour	Correlation Period 1 (Days 1 – 3 post-farrowing)	Correlation Period 2 (Days 4 – 6 post-farrowing)	P Value (diff)
Crate				
Investigate	Udder active	-0.28	0.20	0.03
Touch	Udder active	-0.25	0.36	<0.01
Paw	Udder active	-0.06	0.46	0.02
Touch	Udder inactive	-0.25	0.36	0.04
Bite	Open active	0.30	-0.24	<0.01
Nose	Open active	0.39	-0.06	0.02
Investigate	Massage	-0.22	0.17	0.03
Touch	Massage	-0.26	0.29	<0.01
Paw	Massage	-0.01	-0.39	0.03
Pens				
Vocal piglet	Udder active	-0.39	0.00	0.03
Bite	Creep active	0.64	0.25	0.01
Nose	Creep active	0.65	0.34	0.02
Root	Creep active	0.64	0.08	<0.01
Investigate	Creep inactive	0.36	0.29	<0.01
Stand	Open inactive	-0.08	-0.42	0.04
Stand	Vocal sow	0.42	-0.12	<0.01
Lying	Vocal sow	-0.44	0.07	0.01
Bite	Vocal sow	0.44	-0.23	<0.01
Nose	Vocal sow	0.35	-0.09	0.02
Paw	Vocal sow	0.24	-0.20	0.02

When sows were standing, piglets in pens were more likely to be inactive in the creep than piglets in crates in period 1 (P1 = 66.0%; C1 = 57.1%) and period 2 (P2 = 65.8%; C2 = 53.9%) ($P < 0.01$, Table 6.3). Piglets in pens were less active in the open than piglets in crates when sows were standing in period 1 and 2 ($P < 0.01$). Once penned sows were loose, their piglets spent less time active in the creep than in period 1 (P1 = 15.2%, P2 = 12.3%, $P < 0.01$, Table 6.3).

There were no differences in the correlations between piglet behaviours whilst sows in crates were standing in period 1 or 2. In pens there was no correlation in period 1 between the time spent standing by the sow and time spent inactive in the open by the piglets. However, in period 2, the more the sow stood, the less time piglets spent inactive in the open (Table 6.2). The correlation between sows standing, and piglets vocalising towards the sow also changed between period 1 (r = 0.42) and 2 (r = -0.12) in pens ($P < 0.01$, Table 6.2).

When sows were lying, piglets were mostly inactive in the creep, and at the sow's udder (active, inactive, and massaging the udder, Table 6.3). Piglets in pens were more active at the udder when sows were lying in period 2 (30.3%) than piglets in crates (22.6%) ($P < 0.01$, Table 6.3). Penned piglets spent more time massaging the sow's udder (27.9%) than crated piglets (21.2%) in period 2 ($P = 0.01$, Table 6.3). Piglets in crates spent less time inactive at the udder ($P < 0.01$) and more time active in open areas ($P = 0.01$) than piglets in pens when the sow was lying in period 1 and 2.

Table 6.3. Associations between sow posture and piglet – directed behaviour and the behaviour of piglets in crates ($N = 15$) and pens ($N = 16$) in period 1 and period 2 (Lsmean %).

Sow Behaviour	Piglet behaviour	SystemxPeriod[1]				P (Period)	P (System)	P (System x Period x Sow Behaviour)
		C1	P1	C2	P2			
Standing	Udder Active	2.1	2.2	5.8	4.9	<0.01	0.06	<0.01
	Udder Inactive	0.0	0.4	0.1	0.9	<0.01	0.01	<0.01
	Creep Active	19.9[c]	15.2[b]	16.3[b]	12.3[a]	<0.01	<0.01	<0.01
	Creep Inactive	57.1[a]	66.0[b]	53.9[a]	65.8[b]	0.08	<0.01	<0.01
	Open Active	17.5[b]	14.8[a]	17.3[b]	14.6[a]	<0.01	<0.01	<0.01
	Open Inactive	3.5	1.5	6.7	1.5	<0.01	<0.01	0.07
	Massage	1.8	2.0	5.2	4.6	<0.01	<0.01	<0.01
	Vocal Sow	1.5[a]	2.1[b]	1.0[a]	1.2[a]	<0.01	<0.01	<0.01
Lying	Udder Active	24.5[b]	24.6[b]	22.6[a]	30.3[c]	0.03	0.38	<0.01
	Udder Inactive	20.2[c]	22.3[d]	11.8[a]	15.6[b]	<0.01	<0.01	<0.01
	Creep Active	4.4[b]	3.5[a]	5.5[b]	3.1[a]	<0.01	<0.01	<0.01
	Creep Inactive	38.3[a]	40.4[b]	41.2[b]	40.1[b]	0.21	<0.01	<0.01
	Open Active	5.7[a]	5.9[a]	8.1[b]	7.5[b]	<0.01	<0.01	<0.01
	Open Inactive	6.8[b]	3.3[a]	10.9[c]	3.5[a]	<0.01	<0.01	0.01
	Massage	22.8[b]	22.1[ab]	21.2[b]	27.9[c]	0.02	0.90	<0.01
	Vocal Sow	0.5[a]	0.8[b]	0.6[ab]	0.7[b]	0.01	0.02	0.01
Vocalise at piglets	Udder Active	29.4[b]	23.3[a]	25.4[ab]	21.5[a]	0.16	0.09	<0.01
	Udder Inactive	8.2[b]	6.2[ab]	4.9[ab]	4.8[a]	<0.01	0.45	<0.01
	Creep Active	12.9[b]	9.7[a]	15.9[c]	10.7[a]	<0.01	<0.01	<0.01
	Creep Inactive	27.7[a]	39.0[b]	26.6[a]	38.7[b]	0.35	<0.01	<0.01
	Open Active	16.9[a]	19.7[b]	21.6[bc]	22.4[c]	<0.01	0.09	0.01
	Open Inactive	4.8[b]	2.2[ab]	5.7[b]	1.9[a]	<0.01	<0.01	<0.01
	Massage	28.2[b]	20.9[a]	24.3[ab]	20.3[a]	0.44	0.01	<0.01
	Vocal Sow	2.9[a]	4.4[b]	3.2[a]	3.1[a]	0.02	<0.01	<0.01
Investigate	Udder Active	20.1[b]	16.5[ab]	17.8[ab]	15.4[a]	0.52	0.62	<0.01
	Udder Inactive	5.4	6.3	4.0	3.2	<0.01	0.12	<0.01
	Creep Active	17.0[b]	11.3[a]	17.9[b]	10.9[a]	0.39	<0.01	<0.01
	Creep Inactive	29.1[a]	41.0[b]	27.0[a]	45.0[b]	0.07	<0.01	<0.01
	Open Active	21.4[a]	22.9[ab]	26.7[c]	23.8[b]	<0.01	0.23	0.01
	Open Inactive	7.0[b]	1.9[a]	6.6[b]	1.7[a]	0.01	<0.01	<0.01
	Massage	19.2[b]	15.3[a]	16.9[ab]	14.9[a]	0.80	0.31	0.01
	Vocal Sow	2.8[b]	3.5[c]	2.2[a]	2.7[b]	<0.01	<0.01	<0.01
Touch	Udder Active	22.4	21.1	22.1	20.8	0.99	0.77	0.08
	Udder Inactive	6.9	8.0	4.7	5.0	<0.01	0.07	0.02
	Creep Active	15.9[b]	9.9[a]	17.1[b]	11.1[a]	0.03	<0.01	<0.01
	Creep Inactive	27.2[a]	34.1[b]	23.0[a]	35.4[b]	0.42	<0.01	<0.01
	Open Active	20.3[a]	24.9[b]	26.5[b]	25.7[b]	<0.01	<0.05	<0.01
	Open Inactive	7.2[b]	2.0[a]	6.5[b]	1.9[a]	0.02	<0.01	<0.01
	Massage	21.2	18.6	21.0	20.1	0.45	0.70	0.22
	Vocal Sow	2.8[a]	4.1[b]	2.2[a]	3.0[b]	<0.01	<0.01	<0.01

[1]P1 = sows and piglets in pens in period 1, P2 = sows and piglets in pens in period 2, C1 = sows and piglets in crates in period 1, C2 = sows and piglets in crates in period 2.
[abcd]Values with different superscripts differ significantly ($P < 0.05$).

There were no differences in the correlations between piglet behaviours whilst sows were lying in period 1 or 2 in crates (Table 6.2). In pens, there was a moderate negative correlation between sows lying and piglets vocalising towards the sow (r = -0.44) whereas in period 2, there was no correlation between these variables.

Observations of piglets while sows performed piglet-directed behaviour

When sows were touching, investigating, and vocalising towards piglets in period 1 and 2, their piglets were mostly inactive in the creep, active in open areas, and active at the udder (Table 6.3). Piglets in pens were more likely to be inactive in the creep than those in crates when sows touched, ($P < 0.01$) investigated ($P < 0.01$) or vocalised ($P < 0.01$) towards them in period 1 and 2. Piglets in crates were more likely to be active in the creep or inactive in the open compared to those in pens in period 1 and 2 when sows performed piglet-directed behaviour (Table 6.3). In period 1 and 2 piglets in pens vocalised towards the sow more than those in crates when sows were investigating ($P < 0.01$) or touching them ($P < 0.01$).

In crates there was a difference between period 1 and 2 for the correlation between sows investigating piglets, and piglets being active at the udder (C1: r = -0.28, C2: r = 0.20, $P < 0.05$, Table 6.2). This was also the case for sows touching piglets and active behaviour at the udder (C1: r = -0.25, C2: r = 0.36, $P < 0.01$, Table 6.2), and the same relationships were found between touching piglets and inactivity at the udder (C1: r = -0.25, C2: r = 0.36, $P < 0.05$, Table 6.2).

In pens, the correlation between sows vocalising towards piglets was negatively correlated with piglets being active at the udder in period 1. There was no correlation between these variables in period 2 (Table 6.2).

Observations of piglets while sows performed pen and crate directed behaviour

Pen and crate directed behaviour included biting at fixtures, pawing, nosing fixtures, and rooting the floor. When sows performed these activities piglets in both systems were usually inactive in the creep. When sows were nosing, piglets in pens were more likely to be inactive in the creep and less likely to be in open areas (active and inactive) than piglets in crates in period 1 and 2 (Table 6.4). In period 2, once sows in pens were loose, piglets were less likely to be active in open areas (P2 = 10.0%) whilst the sow was biting fixtures compared to piglets in crates (C2 = 16.7%) ($P < 0.01$, Table 6.4). Whilst sows were rooting the floor piglets in both systems were usually in the creep (active and inactive) or active in open areas, though piglets in pens were less likely to be active in the creep (P2 = 9.1%), than piglets in crates (C2 = 14.6%) in period 2 when sows were rooting the floor ($P < 0.01$, Table 6.4).

Table 6.4. Associations between pen and crate directed behaviour by sows and the behaviour of piglets in crates (N = 15) and pens (N = 16) in period 1 and period 2 (Lsmean %).

Sow Behaviour	Piglet Behaviour	Group[1]				P (period)	P (system)	P (system x period x sow behaviour)
		C1	P1	C2	P2			
Bite	Udder Active	13.1	7.3	5.0	2.9	0.13	0.51	0.10
	Udder Inactive	3.9	1.5	0.8	0.4	<0.01	0.95	0.26
	Creep Active	16.8	13.6	18.9	13.1	0.41	<0.01	0.15
	Creep Inactive	48.3[a]	64.4[ab]	56.6[ab]	70.6[c]	0.04	<0.01	0.03
	Open Active	15.9[ab]	10.5[a]	16.7[b]	10.0[a]	0.15	<0.01	<0.01
	Open Inactive	1.9	2.7	2.1	3.0	0.19	0.01	<0.01
	Massage	13.1	6.0	4.7	2.9	0.18	0.32	0.10
	Vocal Sow	0.7	0.7	1.0	0.7	0.43	0.67	0.60
Paw	Udder Active	35.4[b]	6.6[a]	13.4[ab]	4.1[a]	0.10	0.02	0.02
	Udder Inactive	2.5	2.1	0.0	0.0	0.08	0.79	0.73
	Creep Active	7.0[a]	10.2[a]	10.4[a]	20.9[b]	0.01	0.08	<0.01
	Creep Inactive	35.6	73.0	66.7	70.3	0.05	0.01	0.10
	Open Active	13.3	8.1	8.9	4.7	0.71	0.18	0.18
	Open Inactive	6.3	0.0	0.5	0.0	0.79	<0.01	0.21
	Massage	35.4[b]	6.3[a]	13.4[ab]	4.1[a]	0.10	0.01	0.02
	Vocal Sow	1.8	1.2	0.0	0.3	0.89	0.98	0.99
Nose	Udder Active	10.3[b]	6.4[ab]	11.2[b]	2.7[a]	0.77	0.07	<0.01
	Udder Inactive	4.1	2.5	2.0	0.8	<0.01	0.82	0.01
	Creep Active	16.8[b]	15.0[b]	15.6[b]	12.2[a]	0.13	<0.01	0.03
	Creep Inactive	45.5[a]	63.2[b]	50.8[ab]	70.8[c]	<0.01	<0.01	<0.01
	Open Active	17.6[b]	11.2[a]	16.2[b]	11.8[a]	0.06	<0.01	<0.01
	Open Inactive	5.8[b]	1.7[a]	4.2[b]	1.7[a]	0.20	<0.01	<0.01
	Massage	9.6[b]	5.1[ab]	10.2[b]	2.8[a]	0.94	0.04	<0.01
	Vocal Sow	1.5[b]	1.1[ab]	1.4[ab]	0.8[a]	0.49	0.32	0.01
Root	Udder Active	4.3	2.0	8.0	3.7	0.41	0.73	0.35
	Udder Inactive	0.0	1.0	0.0	0.2	0.01	0.42	0.11
	Creep Active	20.1[c]	20.0[c]	14.6[b]	9.1[a]	<0.01	<0.01	<0.01
	Creep Inactive	54.4	63.4	59.9	72.1	<0.05	<0.01	0.10
	Open Active	14.7	13.3	12.3	14.4	0.32	0.90	0.39
	Open Inactive	6.4	0.4	5.3	0.6	0.38	<0.01	0.36
	Massage	4.3	2.0	8.0	3.5	0.37	0.56	0.38
	Vocal Sow	1.5	2.4	1.8	1.4	0.49	0.24	0.33

[1]P1 = sows and piglets in pens in period 1, P2 = sows and piglets in pens in period 2, C1 = sows and piglets in crates in period 1, C2 = sows and piglets in crates in period 2.
[abc]Values with different superscripts differ significantly ($P < 0.05$).

In period 1, there was no relationship between sows in crates pawing whilst piglets were active at the udder. (r = -0.06). However in period 2 the correlation between these behaviours was moderately positive (r = 0.46) ($P < 0.05$, Table 6.2). Sows biting (r = 0.30) and nosing fixtures (r = 0.39) were positively correlated to piglets being active in the open in period 1 in crates. However in period 2, the more time that piglets spent active in open areas in crates, the less time sows spent biting at fixtures (Table 6.2).

Table 6.5. Correlations between gilt posture and behaviour and the behaviour of piglets during days 1 – 3 post-farrowing. Correlations in bold are significant (*P < 0.05*).

Gilt behaviour	Group[1]	Piglet behaviour						
		Udder active	Udder inactive	Creep active	Creep inactive	Open active	Open inactive	Vocalise at gilt
Standing	CC	-0.01	-0.27	0.33	-0.17	**0.58**	0.05	0.35
	CP	-0.08	-0.27	0.24	-0.11	**0.59**	0.32	0.10
	PC	-0.10	-0.40	**0.56**	0.33	**0.68**	0.05	-0.27
	PP	-0.15	-0.10	0.36	-0.05	**0.56**	0.11	**0.80**
Lying	CC	0.02	0.31	**-0.41**	0.16	**-0.65**	-0.05	-0.32
	CP	0.07	0.24	-0.23	0.10	**-0.56**	-0.29	-0.14
	PC	0.12	0.40	-0.42	-0.32	**-0.72**	-0.01	0.25
	PP	0.21	0.14	**-0.41**	0.01	**-0.54**	-0.06	**-0.76**
Vocalise at piglet	CC	-0.01	-0.20	0.09	-0.04	0.01	0.01	0.38
	CP	0.36	0.45	0.20	-0.45	**0.57**	-0.11	**0.64**
	PC	0.11	-0.31	0.32	0.12	**0.54**	-0.31	-0.19
	PP	0.17	0.14	0.50	-0.19	**0.44**	-0.17	**0.65**
Investigate	CC	0.06	-0.35	0.60	-0.02	0.77	-0.25	0.33[ab]
	CP	0.22	-0.21	0.57	-0.08	0.65	0.01	0.19 [ab]
	PC	-0.28	-0.51	0.15	0.45	0.69	-0.21	-0.29[a]
	PP	-0.03	-0.06	0.42	0.05	0.30	-0.24	0.79[b]
Touch	CC	0.10	-0.39	**0.44**	0.12	**0.68**	-0.26	0.08[a]
	CP	0.31	-0.20	**0.49**	-0.13	**0.55**	0.12	0.18[ab]
	PC	-0.28	**-0.63**	0.29	**0.57**	**0.77**	-0.18	-0.23[a]
	PP	0.16	0.13	**0.41**	-0.07	0.26	-0.28	**0.75[b]**
Bite	CC	-0.01	-0.27	**0.49**	-0.02	**0.50**	-0.23	-0.01
	CP	0.10	-0.06	0.23	-0.17	0.14	**0.56**	-0.05
	PC	-0.17	-0.40	0.34	**0.53**	0.31	-0.06	0.20
	PP	0.02	-0.03	0.10	-0.21	**0.47**	0.21	0.16
Paw	CC	-0.11	-0.06	0.03	0.10	0.14	-0.14	0.29
	CP	-0.22	-0.12	0.20	0.16	0.46	-0.20	-0.13
	PC	-0.19	-0.21	0.10	0.38	0.03	-0.18	-0.12
	PP	-0.30	0.24	**-0.43**	**-0.45**	0.26	0.51	0.15
Nose	CC	-0.08	-0.27	0.36	-0.09	0.57	-0.21	0.23
	CP	-0.09	-0.22	0.36	-0.02	0.59	0.08	0.02
	PC	0.14	-0.24	0.46	0.32	0.53	-0.04	-0.18
	PP	-0.19	-0.08	0.19	-0.15	0.62	0.29	0.35
Root	CC	0	-0.34	0.29	-0.15	**0.62**	0.05	0.27
	CP	0.06	-0.31	0.28	-0.12	**0.58**	0.20	0.19
	PC	-0.05	-0.38	0.28	0.32	**0.57**	-0.20	-0.25
	PP	-0.07	-0.09	0.28	0.08	0.31	-0.03	0.44

There were strong positive correlations for sows biting at fixtures ($r = 0.64$), nosing fixtures ($r = 0.65$), and rooting the floor ($r = 0.64$) when piglets were inactive in the creep in period 1 in pens (Table 6.2). In period 2 when sows were loose, they were biting and nosing whilst piglets were inactive in the creep (Table 6.2). Biting, nosing and pawing all had weak positive correlations to piglets vocalising towards the sow in period 1 in pens (Table 6.2).

Observations of gilts and their piglets during the first three days post-farrowing

Observations of piglets whilst gilts were standing and lying

Piglets in the PC group were the most active in the creep compared to all other piglets when gilts were standing ($P < 0.05$, Table 6.5). CC piglets spent the most time inactive in the open ($P < 0.01$) and PP piglets vocalised towards the sow more than all other piglets when gilts were standing ($P < 0.01$, Table 6.5). Piglets in pens (CP and PP) were more likely to be inactive in the creep when the gilt was standing compared to those in crates (CC and PC, $P < 0.01$).

There was a strong positive correlation between PP piglets vocalising towards the gilt whilst the gilt was standing ($r = 0.79$, $P < 0.01$) (Table 6.5). This was the only group to have a significant correlation between vocalising and standing.

Table 6.6. Associations between gilt posture and piglet – directed behaviour and the behaviour of piglets during days 1 – 3 post-farrowing (Lsmean %).

Gilt behaviour	Piglet behaviour	Group[1]				P (born)	P (farrow)	P (born x farrow x gilt behaviour)
		CC	CP	PC	PP			
N		8	6	5	8			
Standing	Udder Active	3.1	0.9	2.4	2.8	0.27	0.55	<0.05
	Udder Inactive	0.5	0.0	0.2	3.9	0.02	0.26	0.13
	Creep Active	13.4^{a}	15.7^{a}	19.4^{b}	16.0^{a}	<0.01	0.61	<0.01
	Creep Inactive	48.5^{a}	57.0^{b}	43.3^{a}	54.8^{b}	0.02	0.03	0.01
	Open Active	17.6^{ab}	21.3^{b}	28.9^{c}	15.5^{a}	0.04	<0.01	<0.01
	Open Inactive	16.7^{b}	3.8^{a}	6.2^{a}	5.6^{a}	<0.01	<0.01	<0.01
	Massage	1.2	0.9	2.2	0.6	0.97	0.90	0.03
	Vocal Sow	0.6^{a}	1.2^{a}	0.3^{a}	2.6^{b}	<0.01	<0.01	<0.01
Lying	Udder Active	18.4^{a}	26.7^{c}	26.7^{c}	23.3^{b}	0.01	0.41	0.02
	Udder Inactive	12.8	17.4	20.4	17.9	<0.01	0.31	0.19
	Creep Active	4.8^{b}	3.7^{a}	3.9^{a}	5.3^{b}	0.01	0.54	0.02
	Creep Inactive	53.0^{b}	42.8^{a}	40.2^{a}	45.8^{b}	<0.01	<0.01	<0.01
	Open Active	5.9^{b}	4.8^{a}	5.6^{ab}	5.0^{a}	0.28	<0.01	<0.01
	Open Inactive	3.7	3.3	4.0	3.2	0.02	<0.01	<0.01
	Massage	14.0^{a}	22.4^{b}	20.7^{b}	14.8^{a}	0.35	0.14	0.01
	Vocal Sow	0.3^{a}	0.2^{a}	0.5^{ab}	0.7^{b}	<0.01	<0.01	<0.01
Vocalise at piglet	Udder Active	29.5^{b}	32.0^{b}	39.7^{c}	22.0^{a}	0.63	0.01	<0.01
	Udder Inactive	5.7	11.4	6.8	8.1	0.02	0.08	0.04
	Creep Active	10.1^{a}	8.9^{a}	10.8^{a}	15.5^{b}	<0.01	0.02	<0.01
	Creep Inactive	33.8	23.6	19.0	34.7	0.06	0.52	0.11
	Open Active	16.1^{a}	21.3^{b}	22.2^{b}	17.5^{a}	0.36	0.51	<0.01
	Open Inactive	4.9	1.6	2.9	2.7	0.77	0.01	0.24
	Massage	21.1^{b}	27.1^{c}	30.5^{c}	10.8^{a}	0.03	<0.01	<0.01
	Vocal Sow	2.4^{a}	2.4^{a}	2.8^{a}	4.4^{b}	<0.01	<0.01	<0.01
Investigate	Udder Active	21.1^{b}	28.7^{c}	26.8^{b}	13.2^{a}	0.21	0.49	<0.01
	Udder Inactive	4.1	6.6	4.9	5.5	0.05	0.37	0.09
	Creep Active	12.3^{a}	12.9^{a}	12.8^{a}	16.7^{b}	0.02	<0.01	0.02
	Creep Inactive	36.5^{a}	25.9^{a}	24.3^{a}	44.1^{b}	0.05	0.27	<0.01
	Open Active	21.7^{b}	24.0^{b}	27.9^{c}	17.9^{a}	0.89	<0.01	<0.01
	Open Inactive	3.2	1.4	2.5	2.4	0.84	0.08	0.87
	Massage	15.3^{b}	23.3^{c}	21.9^{c}	6.5^{a}	<0.01	0.13	<0.01
	Vocal Sow	1.2^{a}	1.3^{a}	2.4^{b}	4.1^{c}	<0.01	<0.01	<0.01
Touch	Udder Active	28.4^{b}	35.7^{b}	28.3^{b}	20.3^{a}	0.03	0.81	<0.01
	Udder Inactive	4.5	7.9	4.3	6.2	0.25	0.28	0.09
	Creep Active	10.2^{a}	10.9^{a}	13.8^{b}	17.9^{b}	<0.01	0.01	<0.01
	Creep Inactive	33.4	15.4	21.6	30.2	0.45	0.14	0.20
	Open Active	20.8^{a}	28.7^{b}	29.8^{b}	22.0^{a}	0.39	0.67	<0.01
	Open Inactive	2.5	1.3	2.1	2.6	0.65	0.32	0.83
	Massage	21.7^{b}	29.0^{c}	23.6^{bc}	11.0^{a}	<0.01	0.35	<0.01
	Vocal Sow	1.7^{a}	0.9^{a}	3.1^{b}	5.3^{c}	<0.01	<0.01	<0.01

[1]CC = born and reared in a crate, farrowed in a crate, $N = 8$, CP = born and reared in a crate, farrowed in a pen, $N = 6$, PC = born and reared in a pen, farrowed in a crate $N = 5$, PP = born and reared in a pen, farrowed in a pen, $N = 8$.
^{abc}Values with different superscripts differ significantly ($P < 0.05$).

Whilst the gilt was lying, CP and PC piglets were more active at the udder ($P = 0.02$) and they massaged the udder more than CC and PP piglets ($P = 0.01$, Table 6.6). CP and PC piglets spent less time in the creep (active and inactive) than CC and PP piglets when the gilt was lying. There was no difference between groups for inactive behaviour at the udder while the gilt was lying (Table 6.6). For all groups it was found that piglets spent more time active in open areas when gilts were standing; and as gilts spent more time lying, piglets spent less time active in open areas (Table 6.5).

Observations of piglets while gilts performed piglet – directed behaviour

Piglets in the PP group were the most vocal of all piglets when piglet-directed behaviour was performed by gilts (Table 6.6). In PP piglets, there were moderate to strong positive correlations between piglets vocalising towards the gilt, and piglet-directed behaviours including vocalising at piglets (r = 0.65, $P < 0.01$), investigating piglets (r = 0.79, $P < 0.01$), and touching piglets (r = 0.75, $P < 0.01$) (Table 6.5). When gilts were vocalising towards piglets, PP piglets were the least likely to be active at the udder ($P < 0.01$) or massaging the udder ($P < 0.01$), and the most likely to be active in the creep ($P < 0.01$, Table 6.6). CP and PC piglets were more likely to be active in open areas and massaging the udder than CC and PP piglets when gilts vocalised towards them ($P < 0.01$, Table 6.6).

Observations of piglets while gilts performed pen and crate directed behaviour

There were no differences in piglet behaviour between groups when gilts were biting at fixtures (Table 6.7). Whilst gilts were pawing, PP piglets were the only piglets inactive in the open ($P < 0.01$, Table 6.7) and these behaviours were positively correlated (r = 0.51, $P < 0.01$, Table 6.3). When gilts were rooting the floor, PP piglets were the least active in the open ($P < 0.01$) and the most vocal towards gilts ($P < 0.01$, Table 6.7). PC piglets were the most active in open areas ($P < 0.01$), and PP piglets were more inactive in open areas ($P < 0.01$) when sows were nosing (Table 6.7). There were no other differences in piglet behaviour when gilts performed pen and crate directed activities.

Table 6.7. Associations between pen and crate directed behaviour by gilts and the behaviour of piglets during days 1 – 3 post-farrowing (Lsmean %).

Gilt behaviour	Piglet behaviour	Group[1] CC	CP	PC	PP	P (Born)	P (Farrow)	P (Born x Farrow x Gilt behaviour)
N		8	6	5	8			
Bite	Udder Active	21.9	22.7	7.7	4.7	0.20	0.99	0.34
	Udder Inactive	0.0	0.0	0.0	11.4	0.39	0.56	0.52
	Creep Active	6.0	4.8	14.6	15.2	0.02	0.93	0.27
	Creep Inactive	58.6	23.1	66.4	45.7	0.48	0.06	0.30
	Open Active	10.4	15.9	8.2	10.3	0.55	0.57	0.80
	Open Inactive	1.0	13.5	3.1	10.5	0.92	0.06	0.10
	Massage	21.9	22.7	7.7	2.1	0.07	0.83	0.23
	Vocal Sow	1.0	0.0	0.0	0.8	0.78	0.91	0.89
Paw	Udder Active	0.0	10.0	0.0	8.0	0.99	0.65	0.97
	Udder Inactive	0.0	1.4	0.0	7.4	0.75	0.81	0.93
	Creep Active	0.0	13.2	0.0	4.8	0.73	0.27	0.23
	Creep Inactive	100.0	58.0	92.3	38.0	0.53	0.09	0.15
	Open Active	0.0	16.1	7.7	19.3	0.56	0.2	0.49
	Open Inactive	0^a	0^a	0^a	20.8^b	0.26	0.30	<0.01
	Massage	0.0	10.0	0.0	7.6	0.90	0.65	0.90
	Vocal Sow	0.0	0.0	0.0	2.1	0.54	0.60	0.53
Nose	Udder Active	9.0	10.8	12.8	3.7	0.97	0.66	0.75
	Udder Inactive	1.3	7.2	6.5	4.0	0.38	0.68	0.95
	Creep Active	4.7	11.2	13.5	12.9	<0.01	0.11	0.08
	Creep Inactive	72.1	52.4	34.4	55.2	<0.01	0.95	0.24
	Open Active	12.1^a	12.5^a	27.5^b	10.7^a	0.01	<0.01	<0.01
	Open Inactive	0.4^a	5.0^a	5.0^a	13.5^b	0.01	0.02	<0.01
	Massage	9.8	9.1	11.3	1.7	0.42	0.31	0.67
	Vocal Sow	0.5	1.0	0.0	1.6	0.41	0.04	0.54
Root	Udder Active	7.4	3.3	5.4	3.2	0.95	0.69	0.35
	Udder Inactive	0.2	0.0	0.8	7.1	0.13	0.47	0.33
	Creep Active	11.3	12.9	16.8	13.4	0.05	0.94	0.22
	Creep Inactive	46.8	61.1	51.1	59.6	0.63	0.13	<0.05
	Open Active	24.8^b	19.7^b	23.9^b	9.0^a	0.04	<0.01	<0.01
	Open Inactive	10.1	3.6	2.8	4.9	0.18	0.17	0.09
	Massage	5.6	2.7	5.4	1.7	0.70	0.50	0.34
	Vocal Sow	0.3^a	0^a	0.4^a	3.1^b	0.01	0.02	<0.01

[1]CC = born and reared in a crate, farrowed in a crate, $N = 8$, CP = born and reared in a crate, farrowed in a pen, $N = 6$, PC = born and reared in a pen, farrowed in a crate $N = 5$, PP = born and reared in a pen, farrowed in a pen, $N = 8$.
[abc]Values with different superscripts differ significantly ($P < 0.05$).

Discussion

Observation of piglets when sows and gilts were standing and lying

The association between the behaviour of sows and the behaviour of their piglets has been investigated previously in farrowing crates only (van Beirendonck, 2014). Some of the general patterns of behaviour are similar between that study and the present findings. Piglets were previously found to be sleeping when sows were lying (van Beirendonck et al., 2014) and in the present study, piglets in crates and pens were mostly inactive in the creep or inactive at the sow's udder when sows and gilts were lying.

When sows were lying, piglets in crates were more active at the udder in period 1 than they had been in period 2, though there was no difference between farrowing systems for this behaviour in period 1. This observation could be related to the development of the teat order. Every piglet has a preferred teat, which they suckle from at each nursing event. Teat order and teat fidelity is usually established within 2 - 4 days after the sow has farrowed (Fraser, 1980; de Passillé et al., 1988). Hence, more non-suckling activity at the udder may be expected during the first 1 – 2 days post-farrowing whilst the sow is lying. However, in pens piglet activity at the udder when sows were lying was higher in period 2 than in period 1, and piglets were more active at the udder than those in crates in period 2. This could be related to sow activity level. Once loose, sows in pens spent more time standing than when they had been crated (Chidgey et al., 2016a). Even when lying down, sows in pens have been observed to be twice as active as those lying down in crates (Blackshaw et al., 1994). Each time the sow changes posture from standing to lying, or moves whilst lying (kicking, rolling, shaking, stretching) it can disturb the piglets. When sows lie down from standing this often captures the attention of the piglets, drawing them to the sow which initiates nosing of the udder and teats (Fraser, 1980).

Piglets in pens massaged the udder more when the sow was lying in period 2 compared to period 1, whereas massaging activity did not differ between period 1 and 2 in crates. Udder massage may be an honest signal of need (Jensen et al., 1998), and the increase in massage activity in period 2 may also relate to greater sow activity once they were loose in pens. Thus once sows are lying, piglets may compensate for a reduced opportunity to access the sow's udder. Such activity may have conveyed a benefit to piglets in pens, as they were heavier at weaning compared to those in crates (Chidgey et al., 2015). This may be related to the positive influence that udder massage has on milk production through increasing blood flow to mammary tissue (Algers, 1993).

In period 1 and 2 piglets in pens spent more time inactive at the sow's udder when she was lying compared to those in crates. No differences were found between groups in the gilt experiment for inactive behaviour at the udder whilst lying. When lying at the udder, piglets benefit from being close to the sow and close to their littermates in terms of keeping warm. Though it is difficult to encourage piglets into the creep given that the sow is a source of comfort, warmth and nutrition (Vasdal et al., 2010; Melisova et al., 2011); . piglets were found to be more attracted to a fellow littermate in a colder environment than they were to a thermal stimulus (Hrupka et al., 2000). Thus a heated creep containing fellow littermates may be an attractive stimulus to piglets.

When gilts were lying, there were no differences between PP and CC piglets in the time spent in the creep (active and inactive), or massaging the udder. Similarly, there were no differences between CP and PC piglets for the same behaviours when gilts were lying, though these piglets spent less time in the creep (active and inactive), massaged the udder more, and were more active at the udder than PP and CC. This could be the influence of the gilt's behaviour, as maternal experience has been shown to have an effect on their offspring (Beattie et al., 1996). Gilts in an unfamiliar environment may need to adapt their behaviour to suit the present surroundings. As pigs can learn through observation (Nicol and Pope, 1994), piglets may acquire information from their dam and their environment in order to adapt to their surroundings. However all gilts were in the same situation considering none had farrowed previously, thus the behavioural differences of gilts and their piglets could be nothing more than variation in individual reactions to parturition and an unfamiliar environment.

When the sow was standing, piglets in pens spent more time inactive in the creep, and less time active in open areas in periods 1 and 2 compared to piglets in crates. Similarly, whilst gilts were standing piglets in pens (CP and PP) were more likely to be inactive in the creep than those in crates (CC and PC). These associations may be linked to the removal of the sow or gilt as a convenient source of heat when they are standing, thus piglets are unable to huddle and rest against the sow. This is the case in crates and in pens, however, in pens the creep area and the open area where the sow is are very different environments. The open area is a large space designed for the sow's comfort and movement, whilst the creep is an enclosed heated zone for the piglets. With the removal of the sow or gilt as a convenient heat source, piglets in pens may be more likely to use the creep when the sow is standing as the larger open area does not meet their thermal requirements. In crates the different zones for sows and piglets exist in a smaller overall space. Thus piglets are usually either close to the sow, close to each other, or close to a radiant heat source with shorter distances between the designated sow and piglet zones within the farrowing space.

Observation of piglets when sows and gilts performed pen and crate directed behaviour

When sows and gilts performed pen and crate directed behaviours, their piglets were mostly inactive in the creep, active at the udder or inactive in open areas. In another study, piglets were found to be walking less when sows were bar biting compared with other sow activities (van Beirendonck et al., 2014). Whilst the present study examined the association between sow and piglet behaviour; the behaviour, activities and postures of sows will also be linked as they are not mutually exclusive. For example, when sows and gilts performed pen and crate directed behaviours, they were usually standing. Piglets are mostly in the creep when the sow or gilt was standing, therefore they would be in the creep when their dam is engaged in any activities whilst standing.

Some of the pen and crate directed behaviours, such as rooting the floor, may be part of the sequence of pre-lying behaviour if performed immediately before lying. In the event that piglets are present in the open area of the farrowing space when the sow attempts to change posture, sows and gilts may be prompted to ensure piglets are not in the way before they lie down (Marchant et al., 1996).

The piglets in crates tended to be more active at the sow's udder than those in pens in period 1 and 2 whilst sows were biting and pawing. The correlation between pawing and activity at the udder changed from very weak and negative in period 1 to moderate and positive in period 2. However, the correlation between pawing and piglets massaging the udder was zero in period 1 and moderate yet negative in period 2 in crates. Thus massaging the udder was not associated with pawing, but other non-suckling activity at the udder was. The behaviour of piglets at the udder has been described as 'frantic' in crates in contrast to the relative 'calmness' in pens; with piglets in crates fighting, climbing over each other, and climbing over the bars of the farrowing crate (Pedersen et al., 2011). Biting and pawing whilst piglets are active at the udder may suggest discomfort or frustration associated with a lack of control, in this case over the amount of time piglets have access to the udder (Deen, 2010). This difficulty would probably persist in crates throughout lactation, but would likely be reduced in loose sows, as the bars of the farrowing crate would no longer impede posture changes such as rolling over to obscure the udder. Other factors such as a lack of enrichment material and confinement itself may be involved, though these conditions are also experienced by sows in pens. Thus it is not clear whether sows in crates tend to express behaviours associated with frustration when piglets are active at their udder, or whether piglets in crates are more active at the udder when sows are biting and pawing compared to piglets in pens.

Observation of piglets when sows and gilts performed piglet-directed behaviour

Piglets in crates and pens tended to be active (at the udder, in the creep, and in open areas) when sows and gilts touched, investigated, and vocalised towards them. In period

2, observations of piglets vocalising towards sows were lower than in period 1 when sows performed piglet-directed behaviours. Sows in pens performed more piglet-directed behaviour once the temporary crate was removed (Chidgey et al., 2015). The decrease in piglet vocalisations towards the sow could relate to an increase in sow-initiated interactions once they were loose. This could also be linked to piglets using other methods such as olfaction and nasal contact to identify their dam. Piglets in crates and pens were often active at the udder and massaging the udder while sows and gilts touched, investigated, and vocalised towards them. This may be possible as piglet behaviours were not mutually exclusive. In a previous study several piglets within the litter were observed to approach the head of the nursing sow and establish naso-naso contact immediately after milk let-down, before returning to the sow's udder to join their littermates for the post-ejection massage (Jensen, 1988). This behaviour disappeared after the fourth week of lactation.

Gilts born and reared in farrowing pens with temporary confinement (PP and PC) vocalised towards their piglets more than gilts born and reared in farrowing crates (CC and CP) (Chidgey et al., 2016b *submitted*). Interestingly, the PP piglets were consistently more vocal towards their dam. In this case it may be the perpetuation of an environment that contributed to this behaviour. No such pattern was evident in CC piglets. In considering the restricted nature of the farrowing crate and limited interactions between sows and piglets in crates it may not be unexpected that behavioural patterns are seemingly lacking in comparison.

Conclusions

During the first 3 days post-farrowing when sows in crates and pens with temporary crating were both confined, there were differences in sow and piglet behavioural associations between these farrowing systems. Thus the farrowing system influenced sow-piglet behavioural associations in different ways. Piglets in pens were generally less active than those in crates when sows were standing, and they were less likely to be inactive in the open areas when sows were lying. Piglets in pens spent more time inactive at the sow’s udder when sows were lying, and they were more vocal towards sows than those in crates, particularly when sows interacted with their piglets. This was also the case in piglets of gilts, as PP piglets vocalised more towards their dam than PC, CP and CC piglets in association with several gilt behaviours. The behavioural associations of the crossover groups (PC and CP) were less clear, which may be caused by the unfamiliarity of the system in which they farrowed relative to their experience in early life.

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Chapter 7

General discussion

Limitations

An increasingly common discussion point in the literature concerning pen – based farrowing systems is that few studies have investigated the performance levels of farrowing pens in a commercial setting (Payne et al., 2011; Morrison et al., 2013). Thus, a key aspect of this thesis was to carry out a large scale investigation of performance, over a number of parameters, on a commercial farm. Collecting data on farm was integral to this research as the emphasis was to reflect a 'real-world' situation where the results would be more relatable to actual conditions rather than a controlled experimental setting. The on-farm nature of this research presented some limitations, as research activities had to be carried out without interrupting day to day on farm activities. Behavioural observations of sows and piglets were limited to normal hours of operation when staff members were present. Furthermore, the duration of behavioural observations was limited to the first six days of lactation due to time constraints, even though some behavioural parameters may have been valuable to observe later in lactation. An example of this is play behaviour in piglets, which is a valuable indicator of welfare (Mellor, 2015) that only begins to develop in piglets at 3 – 5 days of age (Horback, 2014), peaking between 2 and 5 weeks of age (Blackshaw et al., 1997). The farm managers made decisions relating to the duration of confinement of sows pre- and post-farrowing. Invasive procedures were not used (e.g. catheterisation of sows for blood sampling) given that staff were not available to assist in research activities other than weighing sows pre-farrowing and at weaning. Performance data was sourced from a herd recording software program (EliteHerd®), which relied on accurate record keeping and data entry by staff. Staff members were also responsible for determining causes of death as post-mortem examinations were not possible. As with any business, changes to staff are inevitable, and this occurred in the farrowing department during the collection of performance data (Chapter 3). The training of new personnel did have a short term effect on performance, evidenced by the decline in piglets weaned over two farrowing batches. It is important to consider the transitioning of staff when a new farrowing system is implemented on-farm. It was noted that, in an effort to become familiarised with the new pen-based system, staff members were present within the farrowing room more frequently than normal in the first two farrowing batches. This may have had a confounding effect due to disrupting sows that were not used to such a regular presence of humans.

Animal welfare

It was not a goal of this thesis to formulate a value judgement as to which farrowing system was best in terms of animal welfare. Indeed, this is somewhat of a circular argument given that the conclusion depends on whether welfare outcomes are based upon the sow's perspective, or that of the piglets'. For this reason, the evaluation of welfare status within a farrowing system has always been challenging. In all other levels of pork production pigs are housed together based on being at a similar stage of their life. Conversely the sow and her litter are at different stages and as such have very different requirements (Blackshaw et al., 1994; Johnson and Marchant-Forde, 2001). Furthermore, an assessment of welfare may be derived from one or more of the three main welfare orientations. The first orientation is the *biological function* view, whereby welfare is deemed to be good when an animal is healthy, growing, and reproducing well, and good productivity is evident (Mellor and Stafford, 2009). The second is the *affective state*, which emphasises the potential for an animal to suffer or have positive experiences, where good welfare is present when animals are capable of adapting or coping without suffering whilst interacting with other animals, humans, and their surroundings (Mellor and Stafford, 2009). The third orientation is one of a *natural state*, where welfare may be compromised depending on how far the conditions in which an animal is kept deviates from the presumed wild state of their species, and the extent to which an animal can express natural behaviours (Mellor and Stafford, 2009). In some cases, only one of these views may be used to describe the welfare status of an animal, and in others all three may be integrated. Emphasis on one as opposed to another may yield a different conclusion to the question of "which is better?"

In this thesis, performance and behaviour were used to compare two farrowing systems to provide a broader picture when considered together. The general consensus within animal welfare science is that animal welfare as a construct is multidisciplinary, thus a combination of indices should be used in assessing animal welfare status. Animal behaviour is a component that is useful in assessing an animal's welfare status. Behaviour provides an observable, external indicator of internal subjective feelings (Dawkins, 1988). Additionally, behaviour can indicate wellbeing, in suggesting the absence of pain, distress or discomfort (Anil et al., 2002). Additionally, animals can display changes in behaviour in a way that enables a rapid appraisal of whether their welfare status may have changed. A limitation to using behaviour is that behavioural patterns are interpreted by humans and given a particular meaning as to how an animal may feel. There is a risk that these explanations may be anthropomorphic as an assessment of what a behavioural display might mean is subjective, and can vary depending on the situation, the individual animal and the observer. That being said when behavioural indicators are integrated with other parameters; a relative indicator of welfare is still possible when comparing different situations such as housing systems. Hence, performance and behaviour were used together in this thesis to compare two farrowing systems thus producing a broader picture when considered together.

Performance in farrowing crates and pens with temporary crating

One of the most important findings generated from Chapter 3 was that whilst piglet mortality was higher in pens with temporary crating (10.2%) than it was in farrowing crates (6.1%), pre-weaning piglet mortality in both farrowing systems was lower than the New Zealand industry average of 13.5% (Welch, 2012). Thus on a well-managed farm achieving above average performance relative to the rest of the industry *before* installing a pen – based farrowing system, the performance achieved in farrowing pens was also above average and better than expected relative to previous literature (Moustsen et al., 2013; Hales et al., 2015). It follows that an operator's performance-related expectations of transitioning to such a system should be evaluated in the context of their current level of production. This is the combined outcome of factors such as stockmanship, management, genetics, nutrition, health and husbandry that already exist on farm. Nevertheless, the findings in Chapter 3 established that when the aforementioned drivers of performance are the same between farrowing crates and pens with temporary crating, pre-weaning piglet mortality was higher in the pen – based system.

The causes and timing of piglet death was compared between crates and pens with temporary crating. These results support the generally accepted knowledge that most piglet deaths occur in the first three days after farrowing (Marchant et al., 2000).

Chapter 3 reported that a greater proportion of piglets that died were older than 4 days of age in pens (38.8%) than in crates (30.4%). After day 4 post-farrowing a greater proportion of piglets died due to being laid on in pens (42.5%) compared to crates (30.8%). This illustrates the effect of removing the crate from a farrowing system.

Studies of pen – based farrowing systems rarely feature pens with temporary crating. The lack of research involving pens with temporary crating could suggest that these farrowing systems are not seen as an acceptable alternative to farrowing crates, or that perhaps that they do not deliver enough of a perceived improvement in sow welfare given that a crate is still used in these designs. An alternative explanation is that the research has been focused on the 'end goal' of becoming crate free. Therefore a potential pen based replacement for farrowing crates that incorporates a crate in its design is not truly future-proof in the event that farrowing crates are eventually phased out. Given that, technically speaking, farrowing crates have not been completely banned anywhere in the world, we can infer that there are still situations where a crate is the best option, albeit for a short period of time. Therefore temporary crating should be investigated further, as this design has the greatest potential for improving the welfare of the sow during lactation whilst minimising piglet mortality.

An issue relevant to this has transpired in Sweden, where farrowing crates were effectively banned in 2007. A report commissioned by the Swedish Ministry of Agriculture in 2014 found that 500,000 piglets die each year between birth and weaning (O'Dwyer, 2015). This represents a pre-weaning mortality rate of 18% across their pork industry. The decision in 2007 to prohibit the use of farrowing crates led to unacceptably high levels of pre-weaning piglet mortality, and compromised piglet welfare. A research programme was launched in 2015 following this report where host farms were given a special exemption to breach animal welfare regulations to trial farrowing systems that immobilise sows in crates.

The findings in Chapter 3 also illustrated that the farrowing system did not influence sow weight loss during lactation, or a sow's subsequent reproductive performance. This is the first such study to compare farrowing systems based on a number of production parameters that included a sow's subsequent reproductive performance. These findings add to previous work through contributing measures of production upon which evaluations of alternative farrowing systems may be made.

It is becoming more widely acknowledged by researchers, scientists, farmers and animal welfare groups that piglet mortality in non-crated farrowing systems tends to be higher than it is in farrowing crates. The evidence indicates that fewer piglets are weaned per litter, production is reduced, performance outcomes are inconsistent, and piglet welfare may be compromised (Barnett et al., 2001; Andersen et al., 2007). Whilst it was found in Chapter 3 that piglets reared in pens were heavier at weaning, this would not offset the losses resulting from significantly higher piglet mortality in pens compared to crates. As piglet mortality is an economic and a welfare issue, future research should focus on identifying commercially feasible systems (i.e. robust, low cost, safe and easy to operate) and validating these in a commercial setting to develop a better picture of what to expect from these systems in the long-term with regard to consistent performance outcomes. Once the most feasible options have been identified, they could be refined in the interest of making incremental improvements to management and sow and piglet welfare. It may therefore be necessary to determine not only from an economic and scientific viewpoint, but also from an ethical and welfare position, what level of piglet mortality is acceptable in pen – based farrowing systems on the proviso that sow welfare is demonstrably improved relative to that experienced in farrowing crates. In practice, this is very difficult. Choosing a cut-off value to represent the point at which welfare is unacceptable has been done before with behavioural stereotypies. An animal's welfare was said to be compromised if more than 10% of their time was spent performing stereotypical behaviour (Broom, 1983). A similar suggestion was made where welfare was compromised in a group of animals if more than 5% of the group was performing stereotypies at any one time (Wiepkema et al., 1983). Applying the same method to piglet mortality would, as with the previous examples, be arbitrary. Another problem with this approach is that the cut-off value chosen could be wrong, leading to the conclusion that a housing system that negatively impacts wellbeing is acceptable based on the cut-off criteria, and vice versa (Mendl, 1991).

The influence of the farrowing system on sow and piglet behaviour

Sows in both farrowing systems spent the same amount of time lying during days 1 – 6 post-farrowing though there was a tendency for sows in pens to stand more and spend less time lying than sows in crates once they were loose (Chapter 4). Sows in loose pens have been observed lying down for up to 20 hours per day in the first 3 days post-farrowing (Danholt et al., 2011), and in another study sows in loose pens and in farrowing crates lay laterally for 75% of observations during the first 48 hours post-farrowing (Cronin et al., 1994). Lateral recumbency following parturition is not unexpected, given that sows are recovering from the farrowing process and minimising posture changes to reduce the risk of accidentally crushing newborn piglets.

Observations of Wild Boar suggest that at 3 – 7 days post-farrowing the sow would still occupy the nest, spending most of her time with her piglets (Jensen, 1988). Thus confining sows in crates in early lactation (i.e. 3 days following parturition) may not compromise a sow's welfare to the same extent as prolonged confinement past this stage. This could support wider consideration of the use of temporary confinement for a short period in early lactation.

As noted in Chapter 4, the farrowing system had more of an effect on the behaviour of the sow than the behaviour of piglets. Sows in pens touched and investigated their piglets more than those in crates, and once loose, sows in pens stood more, spent more time rooting the floor, and less time lying than when they had been crated. Piglet behaviour was primarily influenced by the day of observation (i.e. their age); hence there were few differences between systems as regards to the general behavioural time budget of piglets (i.e. nursing, resting, and being active). This is interesting, given the findings in Chapter 5 where gilts born and reared in pens behaved differently to gilts born and reared in crates when they first farrowed. Thus the association between sow and piglet behaviour was investigated to determine whether these associations differ between crates and pens with temporary crating, and whether they change once sows are loose in pens. The outcomes from this study suggest that it is the relationship between sow behaviour and piglet behaviour that differs in crates and pens, not necessarily the behavioural time budget. It may be these relationships that influenced the development of behavioural patterns in piglets. For example, Chapter 6 showed that piglets in pens vocalised towards sows more than piglets in crates when sows performed piglet – directed behaviour. This was also the case in the next generation (Chapters 5 and 6), as PP piglets (piglets of gilts that were born and reared in pens and farrowed in pens) vocalised more towards their dam than CC, CP and PC piglets when gilts performed piglet – directed behaviour.

As well as differences between systems, some associations between sow and piglet behaviour changed once sows in pens were released from their temporary crates as was outlined in Chapter 6. When sows in pens were lying, piglets massaged the udder more and spent more time performing non-suckling udder activity when sows were loose, compared to when they had been crated. Piglets vocalised towards sows less when sows were standing once they were loose, compared to when the sow was standing whilst crated. When sows were pawing the floor whilst loose, piglets were more active in the creep than when sows performed these behaviours whilst crated. Piglets in pens spent less time inactive in open areas than piglets in crates (Chapter 4) thus it may be that once sows in pens were loose, their piglets adapted initially by being less conspicuous (i.e. vocalising at the sow less, reducing the time they spent in open areas, and spending more time in the creep when the sow was standing whilst loose).

The early life environment and the transmission of maternal behaviour

Sows in pens interacted more with their piglets than sows in crates (Chapter 4), thus it follows that the piglets reared in pens and crates may have experienced differing levels of maternal care. Chapter 5 presented the first investigation as to whether the behaviour of gilts can be influenced by the system in which they were born and reared. It was found that gilts born and reared in pens vocalised towards and touched their piglets more than gilts born and reared in farrowing crates.

The finding that the early life environment can influence later behaviour may have wider implications for adaptation and animal welfare. Ethically speaking, it is questionable to use a breeding objective to reduce a behavioural problem within a production system, rather than addressing the problem by changing the system or its management (Knap, 2013). However the development of a behavioural trait in response to a specific production system may improve animal welfare if that trait assists adaption to that system (Knap, 2013). As such, the ability to rear gilts that could be better prepared for farrowing and lactating in pen – based systems would be a major advantage. Such traits may include careful pre-lying behaviour (touching, vocalising towards, and investigating piglets before changing posture), and improved responsiveness towards piglets as a result of a more reciprocal relationship between gilts and their offspring. Though a subtle improvement in adaptation to pen – based systems may not lead to significant advancements in performance, there is potential to reduce the variability between individuals that has so far been a barrier to achieving consistent results in these systems. This may be achieved through encouraging the aforementioned maternal behavioural traits that may promote piglet survival. . In turn, the uptake of these alternatives by industry might be improved. Indeed it has been highlighted that one of the most confounding aspects of studies involving alternative farrowing systems is that the sows used in these studies were not reared in those systems (Barnett et al., 2001). It could be argued that the ‘environments’ (crate or pen) in this thesis were not all that different. Both farrowing systems were indoors, had fully slatted flooring, no bedding, maintained a similar thermal environment, and used farrowing crates. Both farrowing systems are still a form of confinement. That being said there were still differences in sow behaviour and in gilt behaviour between the two systems. Even though the only real difference between environments was that sows in pens had more space, this difference was significant enough for sows to exhibit more maternal behaviour towards their piglets.

Considering their design, the two farrowing systems may not appear very different; especially if the 'gold standard' high welfare farrowing and lactation environment (in terms of a sow's behavioural needs) is probably closer to an outdoor system (Johnson and Marchant-Forde, 2009). However there was enough of a difference between the farrowing systems that the behaviour of sows in crates and pens differed (Chapter 4), which influenced the behaviour of the next generation (Chapter 5). A similar observation was made in a study of sow performance in a Family Pen System, an enriched housing system designed to accommodate sows and their litters in family groups. In Family Pens, a boar is introduced three weeks after a sow has farrowed, and the litter remains with the sow until 10 days before the next litter is due to be born (Stolba, 1981; Stolba and Wood-Gush, 1984). Sows that had been reared in this Family Pen system produced 1.3 extra piglets per year than sows which had been sourced from commercial herds (Wechsler, 1996). Pre-weaning piglet mortality was significantly lower in sows which had been reared in Family Pens. However, home – reared sows would have other advantages over sows that were born and reared elsewhere, such as improved immune resistance to on – farm diseases. This would probably be passed on to their piglets, which may have given them a survival advantage (Wechsler, 1996). The experiments in this thesis were all carried out on one farm in order to avoid the confounding effects that would be present if multiple herds had been used.

Final thoughts and future directions

Farrowing pens that have a temporary farrowing crate are designed to minimise piglet mortality relative to loose pens where no crating is used. Temporary confinement is a viable method of reducing piglet mortality in pens, so the management of sows and their litters at this time should be a focus for further investigation. The transition period between being crated and then loose has not been addressed in previous studies, however in a commercial setting it was clear that this period was risky for the piglets. At this time the sows are usually very active whilst they investigate their surroundings, neighbouring sows, and their own piglets. This is the first time that the piglets are exposed to a more dynamic behavioural response from the sow, and the first time that the sow can initiate physical contact with the piglets.

One batch of sows was observed prior to the commencement of the study, for the purposes of becoming familiar with the farm, the staff, and the farrowing department. It was evident from this visit that the sows' reaction to being released from their crates on day 4 was variable. Nursing behaviour however was relatively consistent and synchronised within one farrowing room. At 4 days post-farrowing, the interval between successive nursing events is approximately 45 minutes to one hour. An hour was therefore enough time to enable sows which were lying down and resting when the crate was opened to have enough time to get up and explore the pen and their piglets, then settle again to nurse before behavioural observations began. Additionally, sows which were immediately reactive to the crate being opened had time to explore their surroundings and settle down before they were observed. Whilst this approach appeared to work well during this study; how long it actually takes for sows to adjust to being loose in a pen after a period of confinement was not quantified. Additionally, the piglets need time to habituate to the sow being loose in the pen. This transitional period should be investigated in order to improve our understanding of farrowing systems that temporarily confine the sow, and identify solutions to some of the challenges of pen – based farrowing systems.

As with most studies investigating farrowing systems, piglet mortality was the main indicator of piglet welfare. However there may be some value in recording the frequency of external injuries to piglets. Lesion scoring would provide another dimension to the assessment of piglet welfare in different farrowing systems, rather than just the 'all-or-none' information gained through comparing mortality rates. Starvation, chilling, and some diseases, still affect piglets without being fatal. As such, there is the potential for suffering in those which survive (Rutherford et al., 2011). Recording the incidence of such conditions could add to a comparative assessment of piglet welfare in different farrowing systems.

The advantage of having an inbuilt crate within a farrowing pen is that if a sow is behaving abnormally or aggressively upon being let loose, it is possible to confine her once again if necessary. Whilst this was never an issue during these experiments, it would be useful to explore indicators that could identify sows which may not be suited to a loose farrowing system. For example, restlessness prior to and during farrowing has been correlated with savaging behaviour in gilts (Ahlström et al., 2002), thus stockpersons may be able to identify individuals that could require extra supervision not only post–farrowing, but after being released from their crate.

A related question is how long should sows be confined prior to farrowing. The most important behavioural need in preparturient sows is nest building (Wischner et al., 2009). Confinement during this period is aversive to sows, and misdirected behavioural displays may be evident during this time where there is a lack of space and substrate to engage in nesting behaviour. If a sow remains loose in the pen until after the birth of the first piglet, nesting behaviour may be possible. However, confinement immediately prior to or during farrowing may also be stressful to sows. An abrupt change in their surroundings whilst giving birth, in addition to the sudden appearance and activity of a stockperson, may disrupt the farrowing process (Lensink et al., 2009). This has been implicated in a longer farrowing duration which can increase the rate of stillborn piglets in a litter (Verhovsek et al., 2007; Oliviero et al., 2010). A different approach may need to be considered for gilts, which have never been confined or individually housed for a significant period of time now that gestation stalls are banned in New Zealand. Gilts that were crated late in gestation (day 114 of pregnancy) had longer inter – birth intervals, and a greater rate of stillborn piglets per litter compared to gilts which were introduced late into a loose pen with no crate (Pedersen and Jensen, 2008). The effect of late gestation crating in sows (i.e. with previous experience of crates) was not investigated in the same study, thus it is unknown whether it was the novelty of crating or the timing of crating which influenced the progress of parturition in gilts. It may be valid to consider gilts separately, such as allowing for a habituation period prior to farrowing given that gilts have not experienced confinement in a crate.

Conclusion

The findings presented in the experimental chapters of this thesis contributed to the understanding of sow and piglet performance in farrowing pens with temporary crating in a commercial setting. Sow behaviour was affected by the farrowing and lactation environment. Though they spent the majority of their time lying, sows in pens were more active, and they interacted more with their piglets than sows in farrowing crates. Some of the associations between sow and piglet behaviour changed when sows in pens were let out of their crates, which may be responsible for altering the behavioural development of piglets.

One of the most novel aspects of this thesis was the finding that the behaviour of young female pigs can be shaped in early life by the type of interactions she has with her dam. Sow – piglet interactions in early life influenced the behaviour of gilts towards their own offspring, irrespective of the environment in which the gilts had given birth. In order to explore the full potential and viability for pens with temporary confinement as replacements for farrowing crates, these systems should be investigated further with a focus on the transitional period between sows being crated and being loose. The welfare of the sow and the piglets should always be considered, in order to achieve the best overall outcome in terms of welfare in any farrowing system.

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Appendix One

Statements of contributions to doctoral thesis containing publications for Chapters 3, 4, 5 and 6.

DRC 16

MASSEY UNIVERSITY
GRADUATE RESEARCH SCHOOL

STATEMENT OF CONTRIBUTION TO DOCTORAL THESIS CONTAINING PUBLICATIONS

(To appear at the end of each thesis chapter/section/appendix submitted as an article/paper or collected as an appendix at the end of the thesis)

We, the candidate and the candidate's Principal Supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the candidate's contribution as indicated below in the *Statement of Originality*.

Name of Candidate: Kirsty Laura Chidgey

Name/Title of Principal Supervisor: Professor Patrick C. H. Morel

Name of Published Research Output and full reference:

Chidgey, K. L., Morel, P. C. H., Stafford, K. J. and Barugh, I. W. 2015. Sow and piglet productivity and sow reproductive performance in farrowing pens with temporary crating or farrowing crates on a commercial New Zealand pig farm. Livestock Science 173, 87 - 94.

In which Chapter is the Published Work: Chapter 3

Please indicate either:

- The percentage of the Published Work that was contributed by the candidate:

  and / or

- Describe the contribution that the candidate has made to the Published Work:

  The candidate designed the experiment and collected the data. The candidate analysed the data with input from Professor Morel and wrote the first version of the manuscript. The final version was published after corrections and input from co-authors.

K. Chidgey
Candidate's Signature

18/03/16
Date

P. Morel
Principal Supervisor's signature

18/3/16
Date

GRS Version 3– 16 September 2011

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Name/Title of Principal Supervisor: Professor Patrick C. H. Morel

Name of Published Research Output and full reference:

Chidgey, K.L., Morel, P. C. H., Stafford, K. J. and Barugh, I. W. 2016. Observations of sows and piglets housed in farrowing pens with temporary crating or farrowing crates on a commercial farm. Applied Animal Behaviour Science 176, 12 - 18.

In which Chapter is the Published Work: 4

Please indicate either:

- The percentage of the Published Work that was contributed by the candidate:

  and / or

- Describe the contribution that the candidate has made to the Published Work:

  The candidate designed the experiment, collected the data and analysed the data with assistance from Professor Morel in developing an appropriate statistical model. The candidate wrote the first draft of the manuscript, with changes and corrections completed with input from supervisors (co-authors).

K. Chidgey — Candidate's Signature — Date: 18/03/16

Principal Supervisor's signature — Date: 18/3/16

GRS Version 3– 16 September 2011

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Name/Title of Principal Supervisor: Professor Patrick C. H. Morel

Name of Published Research Output and full reference:

Chidgey, K.L., Morel, P. C. H., Stafford, K. J. and Barugh, I. W. 2016. The performance and behaviour of gilts and their piglets is influenced by whether gilts were born and reared in farrowing pens with temporary crating or farrowing crates. Livestock Science (Submitted).

In which Chapter is the Published Work: 5

Please indicate either:

- The percentage of the Published Work that was contributed by the candidate:

  and / or

- Describe the contribution that the candidate has made to the Published Work:

  The candidate designed the experiment, collected the data and analysed the data with assistance from Professor Morel in developing an appropriate statistical model. The candidate wrote the first draft of the manuscript, with changes and corrections completed with input from supervisors (co-authors).

K. Chidgey
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18/3/16
Date

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In which Chapter is the Published Work: 6

Please indicate either:

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  and / or

- Describe the contribution that the candidate has made to the Published Work:

  The candidate designed the experiment, collected the data and analysed the data with assistance from Professor Morel in developing an appropriate statistical model. The candidate wrote the first draft of the manuscript, with changes and corrections completed with input from supervisors (co-authors).

K. Chidgey — Candidate's Signature | 15/4/16 — Date

Principal Supervisor's signature | 15/4/16 — Date

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