Welfare and Productivity of Sows and Litters in Farrowing Crate Compared to Lactation Pen 1C-113 (1C-104)

Report prepared for the Co-operative Research Centre for High Integrity Australian Pork

By

Paul Hemsworth, Clara Singh, Megan Verdon, Tracie Storey and Maxine Rice

Animal Welfare Science Centre, Faculty of Veterinary and Agricultural Sciences, The University of Melbourne, Parkville, 3010, VIC

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Executive Summary

Farrowing crates were designed both for ease of management and to minimise the incidence of piglets being overlain by the sow. Welfare concerns relating to farrowing crates are largely based on the physical and behavioural restriction of the sow and this has resulted in the increasing interest in and development of alternative farrowing and lactation housing. Most of these alternative systems aim to improve the welfare of the sow by providing greater floor space and thus more opportunity for movement, particularly for turning around, and for more sow-piglet interactions. However, many of these alternative systems are presently not commercially viable because of the increased floor space and thus added capital costs to the producer (due to installation as well as extra management requirements), as well as increased piglet mortality, particularly in the first few days of life. On the other hand, there is some evidence that larger pens are associated with longer periods of milk let-down and greater piglet weight gain. There is also limited evidence that enabling sows more opportunity to interact with their piglets may facilitate social learning in piglets, consequently reducing stress associated with mixing at weaning.

Recent Danish research has shown that temporary housing sows and their litters in farrowing crates only during parturition and early lactation (to days 4 or 7 of lactation) is effective in reducing total piglet mortality to day 10 of lactation. In addition to the use of the farrowing crates for the entire lactation, a Victorian pork producer has also been using loose penning from day 3 of lactation. The main aim of the present project was to examine the welfare implications for piglets of replacing conventional farrowing crates with this alternative system (the lactation pen) from 3 days postpartum until weaning. In comparison to housing in farrowing crates from day 110 of gestation until weaning, it was hypothesised that temporary housing in a farrowing crate from day 110 of gestation to day 3 of lactation results in a similar incidence of piglet mortality but a lower incidence of piglet skin injury and more frequent interaction between sows and piglets. Furthermore, this increased sow-piglet interactions with temporary housing in a farrowing crate, results in increased expression of maternal behaviour, consequently improving piglet play behaviour, and reducing injurious piglet behaviour, such as sucking, chewing and rubbing other piglets.

Two experiments were conducted in the present project. In both experiments after housing in farrowing crates from day 110 of gestation, sows and their litters were randomly allocated from the third day of lactation to either a farrowing crate ('farrowing crate' treatment) or a loose pen ('lactation pen' treatment) until weaning of piglets at 28 days of age. The farrowing crates were conventional farrowing crates providing a crate of 2.0 x 0.6 m with a total floor area of 2.0 x 1.5 m (total floor area of 2.9 m^2) and the lactation pens were 1.8 x 2.5 m (experiment 1) or 1.7 x 2.4 m (experiment 2) providing a total floor area of either 4.5 m^2 or 4.1 m^2, respectively, and had plastic flooring, sloping anti-crush bars and a heated creep (approximately 1.23 x 0.45 m).

In the first experiment, 32 sows and their litters (a total of 343 piglets) were removed from farrowing crates on the third day of lactation (day 1 of treatment) and randomly allocated to either the farrowing crate or lactation pen treatments until weaning at 28 days of age (day 26 of treatment). Piglet growth and sow and piglet skin injuries were recorded for all litters (128 focal piglets for weights). The behaviour of 24 of these litters (96 focal piglets) was also recorded allowing for observations to be made on suckling behaviour (duration, frequency, sow-piglet interactions) and piglet time budgets of behaviour (posture, investigatory behaviour, social behaviour). There were no housing treatment effects on piglet weight gain or skin injuries at days 9 and 16. There were more sow-piglet interactions during and after, but not before, suckling bouts in lactation pens

and sows in this treatment terminated bouts less frequently than those in farrowing crates. Further, piglets in lactation pens spent a greater proportion of time interacting with the sow and playing and less time manipulating other piglets by sucking, chewing and rubbing them. However, more piglets missed suckling bouts in the lactation pens than in farrowing crates.

The second experiment consisted of two parts. Part 1 utilised 28 sows and four focal piglets from each of their litters (n=112 piglets). As in experiment 1, sows and their litters were removed from farrowing crates on the third day of lactation (day 1 of treatment) and randomly allocated to either a farrowing crate ('farrowing crate' treatment) or a loose pen ('lactation pen' treatment) until weaning at 28 days of age. The loose pen in this experiment was slightly smaller than the pen used in experiment 1 (4.5 vs. 4.2 m^2) and had additional changes to the design and positioning of anti-crush rails. The piglet measures recorded in experiment 1 were conducted only on focal pigs in this experiment. Records were taken on piglet weight gain, and sow and piglet skin injuries after day 3 of lactation. Time budgets of behaviour of piglets (posture, investigatory behaviour and social behaviour) were also observed and the behavioural responsiveness of sows to an audio recording of an unfamiliar piglet squealing was assessed ('maternal responsiveness test'). In part 2 of experiment 2 piglet mortality from day 3 of lactation was recorded over 12 months on a total of 331 and 340 litters in farrowing crates and lactation pens, respectively. Sows in lactation pens sustained more fresh and total injuries on days 9 and 16 than those in farrowing crates. While there was no significant treatment effect on fresh injuries in piglets, there was a significant treatment by time interaction on total skin injuries in piglets. Piglets in lactation pens had more total injuries at day 16 than those in farrowing crates. In lactation pens, piglets and sows spent a greater proportion of time interacting and sows stopped feeding and lifted their head more frequently in the maternal responsiveness test. In contrast to experiment 1, there were no treatment effects on the time budget of behaviour of piglets in experiment 2, but in agreement with experiment 1, there were no housing treatment effects on piglet growth. Over 12 months, there was no effect of treatment on piglet mortality from day 3 of lactation.

The increased interaction observed between sows and piglets in the loose pens in both experiments provides evidence of behavioural restriction in crates. The results of experiment 1, but not experiment 2, show that piglets in the lactation pens displayed more play behaviour but less injurious or harmful behaviours such as sucking and chewing other piglets. Sows in lactation pens in experiment 2 had increased maternal behaviour based on the behavioural responsiveness of sows to recordings of piglet vocalisations.

Sows in lactation pens had more fresh skin injuries at days 9 and 16 in experiment 1 and more fresh and total skin injuries at days 9 and 16 in experiment 2. For piglets, there were no housing effects on fresh skin injuries in either experiment 1 or 2, but piglets had more total injuries on day 16 in experiment 2 in lactation pens than in farrowing crates. The skin injuries for both sows and piglets were minor scratches, and may arise with increased floor space in the lactation pens and particularly for piglets with increased play behaviour. Housing sows in lactation pens following temporary confinement in a farrowing crate for 3 days postpartum had no effect on subsequent piglet daily growth or mortality.

These results suggest that increased floor space and opportunity for interaction between sows and piglets in the lactation pens from days 3 to 28 of lactation may result in improved maternal behaviour in sows and improved social behaviour in piglets. While these limited results suggest an improvement in piglet welfare in the loose pens from day 3 of lactation, clearly further and more extensive observations on piglet behaviour, both pre- and post-weaning, and maternal behaviour are required. Examination of the long-term effects on

post-weaning piglet social behaviour and growth performance is required because of the potentially important early experiential effects. The lack of housing treatment effects on the social behaviour of piglets in experiment 2 may be due to the slightly smaller lactation pens in the experiment (4.2 vs. 4.5 m^2 in experiment 1) and thus the implications of pen space on piglets also clearly warrants further study. Finally, comparisons of piglet injuries and mortality in the period following the transfer of sows to lactation pens until weaning are limited, and thus research on design features and their location in the lactation pen to protect piglets and assist sows when changing posture, particularly near vertical structures, may ensure amelioration of both injuries in sows and piglets and mortality in piglets.

In conclusion these findings indicate that housing sows and their litters in lactation pens following temporary confinement in a farrowing crate early in lactation when the risk of piglet mortality is high, offers an opportunity to minimise piglet mortality while reducing welfare risks to both sows and their piglets. For those producers that are interested but hesitant in transitioning to a totally confinement-free system, temporary confinement early post-partum appears to provide an intermediary step that offers an overall improvement in both sow and piglet welfare before transitioning to a totally confinement-free system.

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1. Introduction

Australian and European surveys indicate that the public appears to be more concerned about the welfare of poultry and pigs than other farm animals (European Commission, 2007; Coleman, 2008). This concern is presumably due to restrictions in space, social contact and choice of stimuli for interaction which are associated with the confinement of animals (Matthews and Hemsworth, 2012). The majority of sows internationally are confined in farrowing crates during parturition and lactation (Barnett et al., 2001; Johnson and Marchant-Forde, 2009) and the purpose of the farrowing crate is basically to physically restrict the movement of the sow to prevent crushing her piglets. With the growing societal concern for animal welfare, there is an increasing interest in alternative farrowing and lactation systems.

The typical social unit for pigs in wild populations is a basic and relatively stable group of 2-4 related sows and their associated offspring, call a sounder (Mauget, 1981). Just prior to parturition pregnant sows will leave their sounder to seek a safe and isolated area to build a nest for farrowing and nursing their piglets (Gonyou, 2001). Sows remain very close to their litters for 1-2 days after farrowing and in this time forage very little (Johnson and Marchant-Forde, 2009). When piglets are approximately 1-2 weeks of age, the sow will gradually socially integrate them into the sounder (D'Eath and Turner, 2009). Thus, sow maternal behaviour has evolved to favour piglet survival and maturation through provision of warmth and nourishment, protection from predators and vertical social learning. To contrast, farrowing crates used during farrowing and lactation restrict sows in their movement and interaction with their piglets. Research has shown that sows restrained in crates direct less behaviour toward their piglets, vocalise less to piglets and are less responsive to piglet vocalisations (Cronin et al., 1996), suggesting reduced maternal behaviour. There is also limited evidence that piglets reared in farrowing crates may be deprived of some benefits relating to social development such as play behaviour (Oostindjer et al., 2010, 2011a). These concerns have prompted development of alternative farrowing and lactation housing designs that provide greater floor space and increased opportunities for social and exploratory behaviour in sows and piglets.

Increasing floor space for sows during lactation may improve sow welfare by enabling them to turn around and freely interact with their piglets. In turn, improvements in sow maternal behaviour may have welfare benefits for piglets as nest building activity, response to piglet distress calls, nose contact with piglets during posture changes and restlessness when piglets are removed are reported to negatively correlate with risk of piglet crushing (Andersen et al., 2005). On the other hand, increased space can lead to a greater risk of piglet crushing (Edwards and Fraser, 1997; Barnett et al., 2001).

Traditionally lactating sows are housed in farrowing crates to reduce piglet mortality. Alternatively, lactating sows can be loose housed in individual pens that increase the opportunity for sows to move around which is thought to improve sow welfare. The majority of studies indicate that piglet mortality is lower in farrowing pens than loose housed in individual pens (see review by Morrison et al., 2012). The majority of pre-weaning piglet mortalities occur within the first day postpartum (Holyoake et al., 1995; Marchant et al., 2000), and are mainly caused by crushing and starvation (Dyck and Swierstra, 1987; Pedersen et al., 2006). As

such, recent research has examined the option of confining sows only during the early period post-parturition when the risk of piglet mortality is high. This research has shown that brief confinement only around parturition and early lactation when piglet mortality is most at risk in loose farrowing-lactation systems is effective in maintaining early lactation mortality rates similar to that achieved with conventional farrowing crates (Moustsen et al., 2013; Hales et al., 2015b). For example, Moustsen et al. (2013) used a specially designed swing-aside combination farrowing pen measuring 2.6 m x 1.8 m ("combi-pen"), where the sows could be kept loose or in a crate to examine the effects of temporary confinement during parturition and early lactation on piglet mortality. Total piglet mortality to day 10 of lactation was highest when sows were loose housed from day 110 of gestation to day 10 of lactation than when sows were confined from the commencement of farrowing to either day 4 or 7 of lactation. These results indicated that temporary confinement only during parturition and early lactation may be a valuable intermediary setup before transitioning to a totally confinement-free system, allowing design and management factors to be further improved while maintaining piglet survival.

The main aim of this project was to examine the welfare implications for piglets of replacing conventional farrowing crates with an alternative system (the lactation pen) from 3 days postpartum until weaning. In comparison to housing in farrowing crates from day 110 of gestation until weaning, it was hypothesised that temporary housing in a farrowing crate from day 110 of gestation to day 3 of lactation results in a similar incidence of piglet mortality but a lower incidence of piglet injury and more frequent interaction between sows and piglets. Furthermore, this increased sow-piglet interactions with temporary housing in a farrowing crate, results in increased expression of maternal behaviour, consequently improving piglet play behaviour, and reducing injurious piglet behaviour, such as sucking, chewing and rubbing other piglets.

2. Methodology

2.1. Experiment 1. Temporary confinement of the lactating sow to day 3 postpartum: effects on pre-weaning piglet and sow behaviour, injuries and growth.

2.1.1. Animals and housing

All animal procedures were conducted with prior approval obtained through The University of Melbourne Animal Ethics Committee. This experiment was conducted in a sow farrowing and lactation unit, in central Victoria, Australia, and commenced in May, 2013 and concluded in March, 2014. All aspects of daily animal husbandry were managed by production staff according to their normal practice.

The animals studied were 32 crossbred (Landrace x Large White) sows of mixed parity and their litters (a total of 343 piglets) over four time replicates (eight sows

per replicate). Sows were housed in groups of 35 at weaning and in groups of five familiar sows from insemination until pregnancy confirmation. After pregnancy confirmation (approximately 5 weeks of gestation) sows where mixed into groups of approximately 17 sows (approximately 1.6 m^2/sow) until they were moved to farrowing crates 7 days prior to parturition. During gestation sows were floor fed 2.4 kg/sow once per day in the morning and via eight overhead feed hoppers spread over the length of the pen. At day 3 postpartum each sow and litter unit were randomly allocated to either a control (farrowing crates) or experimental (lactation pens) treatment group, and transferred to their respective housing treatments (experimental day 1). Piglets' teeth were clipped at birth. Average litter sizes for the herd over the period from December 2013 to December 2014 were 11.1 total piglets born alive, 10.4 piglets at day 3 of lactation (prior to transfer into lactation pens) and 9.8 piglets weaned, per litter. Sows and piglets remained in their treatment pens until piglets were weaned at approximately 25 days of age.

The farrowing crates (crate 2.0 x 0.6m, total area 2.0 x 1.5m) used were typical of conventional systems, with a space allowance of approximately 1.2m^2 that did not allow sows to turn around (Figure 1a). The lactation pens (1.8 x 2.5m) used for the experimental group in this study provided a floor space of 4.5m^2 and had plastic flooring, sloping anti-crush bars and a heated creep (approx. 1.23 x 0.45 m) (Figure 1b). Sows from farrowing crate and lactation pen treatments were housed in the same shed. The crates and pens were located on the west side of the shed, but on opposite sides of the aisle.

Both farrowing crates and lactation pens were fitted with a built in trough for feed delivery and water was supplied *ad libitum*. During lactation sows were fed a standard commercial lactation pelleted diet (13.7 MJ/kg DM, and 17.85% protein). Sows were manually fed 4.0 kg/day in the morning, with a top up offered in the afternoon as required. Creep was offered to piglets from 12 days of age until weaning.

(a) (b)

Figure 1. Farrowing crate (a) and lactation pen (b).

2.1.2. Measurements

Sow and piglet behaviour

The behaviour of 24 sows and 96 piglets (4 focal piglets per litter) was observed directly and indirectly using cameras. Focal piglets were selected randomly, balancing for sex and excluding any obvious runts.

Suckling behaviour

Suckling behaviour and sow-piglet interactions were observed continuously on days 2, 9 and 16 of the experimental period between the daylight hours of 0700 and 1700 h from video recordings by overhead cameras. Table 1 provides a description of sow and piglet behaviours around suckling that were recorded.

Table 1. Description of sow and piglet behaviour observed around suckling.

Suckling bout	A bout of suckling where at least 75% gather at udder and massaging and/or suckling occurred for at least 1.5 min.
Start of suckling bout	75% of piglets gather at udder and begin massaging.
End of suckling bout	75% of piglets have stopped massaging (became still or moved away from the udder) or sow terminates massage/suckling by changing posture.
Sow-piglet interaction	Interaction with the piglet in which the sow moves her head to make physical contact with piglet, pausing and maintaining contact for at least 1 s. Interactions were recorded 2 min before, during and 2 min after suckling.
Piglets that missed suckling bout	Piglets absent from udder (not suckling/massaging or attempting to) for a majority of suckling bout duration.
Displacement at udder	A piglet is displaced from the udder (becomes detached from the teat and has to walk outside or over the cluster of piglets to claim new position) during suckling bout, when 75% piglets are still suckling/massaging and prior to milk letdown (75% piglets still, finished when first piglets resumes massage). Does not include piglets that leave the udder and do not return immediately and resume suckling/massage

Piglet behavioural time budgets

Piglets were observed for a total of 4 h per day at days 2, 9 and 16. From video recordings, one observer recorded piglet behaviour using instantaneous point sampling (Martin and Bateson, 2009) at 30 s intervals. These observations were conducted in 1-h periods commencing at 0800, 0910, 1020 and 1130 h, resulting in a total of 60 sample points per day per pen/crate. The observations of piglet behaviour are described in Table 2.

Table 2. Description of the behaviour observed in studying the time budget of behaviour of the piglets (adapted from Oostindjer et al., 2011c).

Lying/inactive	Lying or sitting, not engaged in activity.
Walking/standing	Standing or walking but not otherwise engaged in activity (includes urinating and defecating).
Suckling/udder massage	Either mouth on teat or nose contact to udder with vertical head movements.
Investigatory behaviours	
– Investigating pen/floor/sow body	Sniffing, touching, biting, rooting, pawing or rubbing any part of the pen, floor or sow's body other than head.
– Investigating food/water	Sniffing, touching, pawing, eating or drinking food or water.
Social behaviours	
– Nosing other piglet	Touching or sniffing any part of the head or nose of another piglet.
– Manipulative behaviour	Nibbling, sucking, chewing or rubbing with nose any part of the body of another piglet.
– Aggression	Ramming, pushing or biting another piglet.
– Mounting	Standing on the back of another piglet with front legs.
– Play	Shaking head, pivoting, jumping, or running with bouncy or jerky movements.
– Interacting with sow	Sniffing, grunting or nuzzling sow's head.

Skin injuries

Each of the 32 sows and their litters (n=343 piglets) were injury scored on experimental days 9 and 16. The same assessment described by Karlen et al. (2007) was used to assess skin injuries for individual sows and four focal piglets from each litter, however in this experiment only fresh lesions were recorded (i.e any skin injury that appeared red or inflamed indicating it had been obtained recently). Each lesion was described as a scratch, abrasion, ulcer, or cut and further categorised according to location on the body (see Karlen et al., 2007).

Piglet growth rate

Four focal piglets (selected randomly, balancing for sex and excluding any obvious runts) from each of the 32 litters (n=128 piglets) were weighed at the start of the experiment (approximately 3 days of age) and again at weaning. These data were used to calculate the average growth of the piglets in each litter from day 3 (g/day).

2.1.3. Statistics

All data were analysed using the statistical package, SPSS Statistics. The following data did not fulfill the assumption of normality (Q-Q plots and histograms, SPSS statistical package, SPSS 17.0, SPSS Inc., Chicago, Illinois, USA) and were square root transformed: suckling behaviours (suckling bout duration, piglet absent from udder, displacement at udder); behavioural time budgets (investigating food/water, nosing other piglets, manipulative behaviour, aggression, mounting and play); and skin injuries (both piglet and sow injuries, days 9 and 16). Data

that were greater than the 75th percentile plus 1.5 x the interquartile range (IQR), or less than the 25th percentile minus 1.5 x ICR were removed as statistical outliers (Pallant, 2013).

Measurements were calculated for each piglet studied (either the entire litter for injuries or the four focal piglets in the litter for weight gain and behaviour) and then averaged for each litter. Analysis of variance for repeated measures (SPSS statistical package, SPSS 17.0, SPSS Inc., Chicago, Illinois, USA) was used to examine treatment effects as well as time effects on sow and piglet behavioural measures (both suckling behaviour and behavioural time budgets) and on sow and piglet injury scores. Replicate was included in the model as a fixed factor. When a significant treatment x day interaction occurred, a univariate ANOVA was performed on each time point to determine where treatments differed. A univariate ANOVA was used to examine treatment effects on piglet weight gain. For this analysis, time replicate was included in the model as a random variable.

2.2. Experiment 2. Temporary confinement of the lactating sow to day 3 postpartum: effects on pre-weaning piglet welfare and productivity and on sow maternal responsiveness.

2.2.1. Animals and housing

All animal procedures were conducted with prior approval obtained through The University of Melbourne Animal Ethics Committee. This study was conducted in a sow farrowing and lactation unit, in central Victoria, Australia and commenced in July 2014 and concluded in August 2014. All aspects of daily animal husbandry were managed by farm staff according to their normal practice.

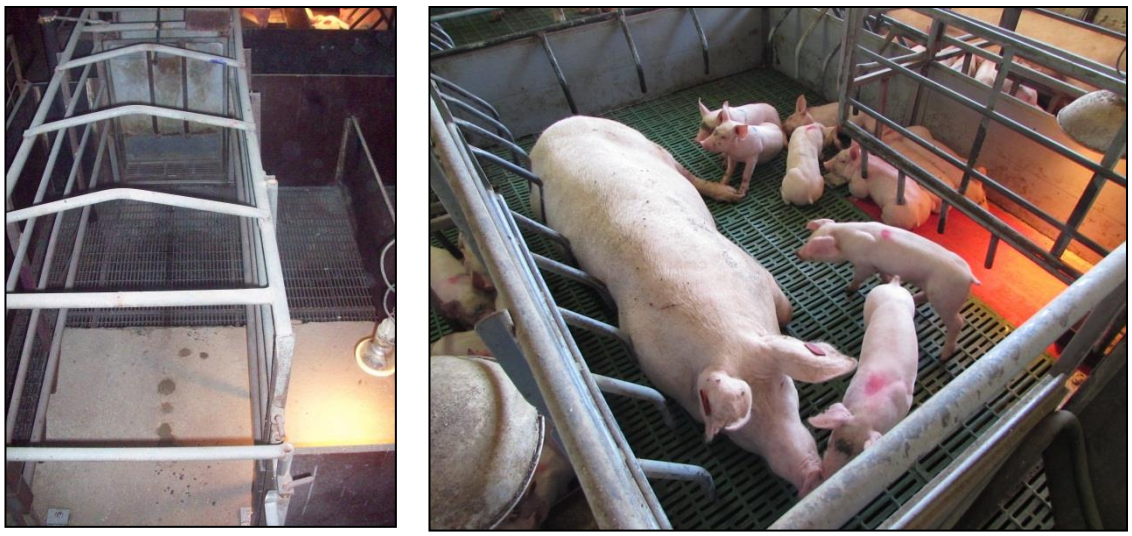
This study consisted of two parts. Part 1 commenced in July and concluded in August 2014 and utilised 28 crossbred (Landrace x Large White) sows of mixed parity and four focal piglets from each of their litters (a total 112 piglets). Part 2 was a retrospective study conducted using the reproductive data of 672 Landrace x Large-White sows (parity 1 – 10) that farrowed in the 12 months from December 2013 were examined.

As standard practice on this specific piggery, sows were housed in groups of 35 at weaning and in groups of five familiar sows from insemination until pregnancy confirmation. After pregnancy confirmation (approximately 5 weeks of gestation) sows where mixed into groups of approximately 17 sows (approximately 1.6 m^2/sow) until they were moved to farrowing crates 7 days prior to parturition. During gestation sows were floor fed 2.4 kg/sow once per day in the morning via eight overhead feed hoppers spread over the length of the pen. At 3 days postpartum each sow and litter unit was randomly allocated to either a control (farrowing crates) or experimental (lactation pens) treatment group, and transferred to their respective housing treatments (experimental day 1). Piglets' teeth were clipped at birth. Average litter sizes for the herd over the period from December 2013 to December 2014 were 11.1 total piglets born alive, 10.4 piglets at day 3 of lactation (prior to transfer into lactation pens) and 9.8 piglets weaned,

per litter. Sows and piglets remained in their treatment pens until piglets were weaned at approximately 25 days of age.

As in experiment 1, the farrowing crates used were typical of conventional systems (crate 2.0 x 0.6m, total area 2.0 x 1.5m) and did not allow sows to turn around (see Figure 3a). However, the design of the lactation pen in the present experiment differed slightly to that described in experiment 1 (Figure 3b). Specifically, the lactation pens used in the present experiment were slightly smaller in floor space (1.7m x 2.4m, total area of 4.08m^2). In addition, the anti-crush guards in the present experiment extended further from the wall and at a curved angle in comparison to the lactation pens in experiment 1. Finally, a metallic leg at the creep area was moved from near the corner of the creep to the center of the creep wall, as piglets were getting caught and injured in the small space. As in experiment 1, the lactation pen flooring was plastic.

Sows from farrowing crate and lactation pen treatments were housed in different yet adjacent sheds. In each shed, farrowing crates/pens were on the west side of the shed and over two sides of the aisle. Both farrowing crates and lactation pens were fitted with a built in trough for feed delivery and water was supplied *ad libitum*. During lactation sows were fed a standard commercial lactation pelleted diet (13.7 MJ/kg DM, and 17.85% protein). Sows were manually fed 4.0 kg/day in the morning, with a top up offered in the afternoon as required. Creep was offered to piglets from 12 days of age until weaning.



(a) (b)

Figure 3. Farrowing crate (a) and lactation pen.

2.2.2. Measurements

PART 1

Four focal piglets were selected from each of the 28 litters (n=112 piglets) for measures of productivity, skin injuries, and behaviour. Focal piglets were selected randomly, balancing for sex and excluding any obvious runts.

Behaviour

Piglet behaviour

Overhead cameras continuously recorded each sow and litter at days 2, 9 and 16 of the experiment. From the video recordings, one observer recorded focal piglet behaviour using instantaneous point sampling (Martin and Bateson, 2009) at 30 s intervals. These observations were conducted from 1100 to 1300 h, resulting in a total of 240 sample points per day per pen/crate. The observations of piglet behaviour are described in Table 6.

Table 6. Description of the behaviour observed in studying the time budget of behaviour of the piglets (adapted from Oostindjer et al., 2011c).

Lying/inactive	Lying or sitting, not engaged in activity.
Walking/standing	Standing or walking but not otherwise engaged in activity (includes urinating and defecating).
Suckling/udder massage	Either mouth on teat or nose contact to udder with vertical head movements.
Investigatory behaviours	
– Investigating pen/floor/sow body	Sniffing, touching, biting, rooting, pawing or rubbing any part of the pen, floor or sow's body other than head.
– Investigating food/water	Sniffing, touching, pawing, eating or drinking food or water.
Social behaviours	
– Nosing other piglet	Touching or sniffing any part of the head or nose of another piglet.
– Manipulative behaviour	Nibbling, sucking, chewing or rubbing with nose any part of the body of another piglet.
– Aggression	Ramming, pushing or biting another piglet.
– Mounting	Standing on the back of another piglet with front legs.
– Play	Shaking head, pivoting, jumping, or running with bouncy or jerky movements.
– Interacting with sow	Sniffing, grunting or nuzzling sow's head.

Maternal responsiveness test

On the morning of days 9 and 16 of the experiment, the behavioural responsiveness of sows to an audio recording of an unfamiliar piglet squealing was assessed. This test involved playing a pre-recorded sound of a piglet squealing from a portable stereo (80 decibels) and observing the response of the sows. The observer holding a portable stereo walked slowly down the aisle while sows were consuming their morning feed stopping for 3 s in front of each crate/pen to record the behaviour of the sow. These observations were conducted six times in

succession (i.e., six tests per sow). This test was adapted from that used by Cronin et al. (1996). However, so that each sow would be exposed to the same stimuli, this study used a sound recording of an unfamiliar piglet for all sows. The sow behaviours recorded in the maternal responsiveness test include head up (number of tests, out of the six tests, in which then sow looks up from feeding), grunt occurrence (the number of tests, out of the six tests, in which the sow grunts in direction of observer or own piglets) and grunt frequency (the total number of grunts from the sow in the direction of the observer or her own piglets, over the six tests).

Skin injuries
Skin injuries of sows and focal piglets were assessed on experimental days 2, 9 and 16 of treatment. Each lesion was described as scratch, abrasion, ulcer, old lesion or cut and further categorised according to location on the body (see Karlen et al., 2007). This allowed for both fresh (scratch, abrasion, ulcer and cut) and total (fresh plus old skin lesions) for each animal to be calculated.

Piglet growth rate
Each focal piglet was weighed at day 2 of the experimental period (i.e., at the 4th day of age), and again at weaning so that the average weight gain per day (g/day) over the experimental period could be calculated.

PART 2

Mortality
Production records obtained allowed for the calculation of the number of piglets at transfer to farrowing crate or lactation pen (day 3) and both the number of piglet mortalities and the % of piglet mortalities (% of piglets alive at transfer that died over the lactation period until weaning) from day 3 until weaning.

2.2.3. Statistics

All data were analysed using the statistical package, SPSS Statistics.

PART 1

The following data did not fulfill the assumption of normality (Q-Q plots and histograms, SPSS statistical package, SPSS 17.0, SPSS Inc., Chicago, Illinois, USA) and were square root transformed: behavioural time budgets (investigating pen, investigating food/water, manipulating piglets, interacting with sow, mounting, play and aggressive behaviour); and skin injuries (total injuries for sows, fresh injuries for sows and piglets). Data that were greater than the 75th percentile plus 1.5 x the interquartile range (IQR), or less than the 25th percentile minus 1.5 x ICR were removed as statistical outliers (Pallant, 2013).

Measurements were calculated for each of the four focal piglets in each litter and then averaged over the focal piglets for each litter. Analysis of variance for repeated measures (SPSS statistical package, SPSS 17.0, SPSS Inc., Chicago, Illinois, USA) was used to examine treatment effects as well as time effects on piglet behavioural time budget measures and injury scores. When a significant treatment x day interaction occurred, a univariate ANOVA was performed on each

time point to determine when treatments differed. Weight gain data were analysed using univariate analysis of variance and a Mann-Whitney U Test was used to test for treatment differences in the maternal responsiveness test.

PART 2

Differences between treatments in parity and the number of piglets at transfer assessed using univariate ANOVA. Data on the number of piglets at transfer did not fulfill the assumption of normality (Q-Q plots and histograms, SPSS statistical package, SPSS 17.0, SPSS Inc., Chicago, Illinois, USA) and were square root transformed prior to analysis.

Data on piglet mortality (number of piglets that died per litter from transfer (day 3 of lactation) to weaning) were discrete. A GLM with an underlying Poisson distribution (SPSS statistical package, SPSS 17.0, SPSS Inc., Chicago, Illinois, USA) was fitted to this variable. This function transforms data to a linear regression with a logarithmic function. Treatment, sow parity and the week of farrowing and the corresponding two and three-way interaction terms were included in the model, while number of piglets at transfer was included as a covariate. If an interaction term was not significant ($P>0.05$), it was removed from the model.

For simplicity, sow parities 6-10 were grouped into a single category of sows greater than or equal to parity 6 (sows ≥ parity 6, 185 sows, 27.5% of total sows). Twelve sows farrowed twice in the recorded period (1.79%). For these sows, each farrowing was recorded and analysed as separate data.

3. Outcomes

3.1. Experiment 1. Temporary confinement of the lactating sow to day 3 postpartum: effects on pre-weaning piglet and sow behaviour, injuries and growth.

Sow and piglet behaviour

Suckling behaviour

As shown in Table 3, neither the number of suckling bouts, duration of suckling nor duration of the interval between bouts differed significantly between treatments ($P>0.05$). Day had a significant effect on both the number of suckling bouts ($P<0.01$) and suckling bout duration ($P<0.01$), with bouts highest at day 9 and decreasing by day 16. Accordingly, the duration of intervals between suckling bouts also decreased at day 9 and increased at day 16 for both treatments ($P<0.01$). Suckling bout duration declined over time in both housing treatments. No day × treatment interactions were evident for these suckling behaviour variables ($P>0.05$).

Frequency of sow-piglet interactions during the 2 min immediately prior to suckling was unaffected by housing treatment ($P>0.05$), day ($P>0.05$) or a day × treatment interaction ($P>0.05$). However, sow-piglet interactions during suckling bouts were affected by treatment, with a more interactions observed in lactation

pens ($P<0.05$). Day also had an effect ($P<0.01$), with the frequency of interactions decreasing over time. There was a significant treatment x day interaction on the frequency of sow-piglet interactions during the two minutes immediately post suckling ($P<0.01$) with more sow-piglet interactions during two minutes immediately post suckling in the lactation pens at day 16 ($P<0.01$) but not at day 2 ($P=0.56$) nor at day 9 ($P=0.10$). When total sow-piglet interactions around suckling were analysed as a single measure (as a sum of pre, during and post suckling interactions), the frequency generally declined over time in both pens and crates ($P<0.05$) but much more substantially in the farrowing crates, reflected in a significant interaction effect between treatment and day ($P<0.01$). The treatments differed at day 9 ($P<0.01$) and day 16 ($P<0.01$), but not at day 2 ($P=0.52$).

There was a day × treatment interaction effect on the number of piglets that missed suckling bouts ($P=0.02$). More piglets missed suckling bouts in lactation pens at day 16 ($P<0.01$) but not at days 2 ($P=0.67$) or 9 ($P=0.09$). Overall, the frequency of displacements declined over time in both treatments ($P<0.01$), but there was no effect of treatment ($P>0.05$) or treatment x day interaction ($P>0.05$). Both treatment and day affected the proportion of bouts terminated by the sow ($P=0.04$ and $P<0.01$, respectively). More sows housed in crates terminated suckling bouts and in general there was an increase over time in bouts terminated by sows ($P<0.01$).

Piglet behavioural time budgets

Frequencies of piglet behaviours were expressed as proportions of sample points in which the behaviour was observed. As shown in Table 4, treatment effects were apparent for several piglet behaviours. The frequency of manipulative behaviours was higher ($P=0.05$) in farrowing crates whereas the frequencies of interactions with sow and play behaviour were higher in lactation pens ($P=0.02$ and $P=0.05$, respectively). Time spent lying showed a general reduction over time ($P<0.01$), whereas investigatory behaviours (investigating the pen ($P<0.01$) and investigating/eating food ($P<0.01$)), as well as some social behaviours (aggression ($P<0.01$), manipulative behaviour ($P<0.01$) and play ($P=0.01$)) generally increased over time. Nosing pen-mates was observed most frequently at day 9 ($P=0.03$). There were no interaction effects between treatment and day for any piglet behaviours ($P>0.05$).

Table 3. Effects of housing treatment on sow and piglet suckling behaviour in suckling bouts between 07:00 – 17:00 h in experiment 1.

Main effects	Day	Means		SEM	P-value		
		Crates	Pens		Treatment	Day	Treatment x Day
No. of suckling bouts	2	14.0	14.92	0.47			
	9	14.7	15.83	0.47	0.17	<0.01	0.96
	16	12.8	13.83	0.40			
Bout duration (s) [1]	2	21.5 *(461)*	19.4 *(376)*	0.50			
	9	19.9 *(396)*	19.6 *(385)*	0.35	0.12	<0.01	0.09
	16	17.5 *(306)*	17.7 *(311)*	0.35			
Bout interval (s)	2	2636	2438	82.2			
	9	2488	2299	76.2	0.13	<0.01	0.99
	16	2867	2654	83.4			
No. sow-piglet interactions							
2-min pre-suckling	2	1.69	1.59	0.18			
	9	1.23	1.39	0.11	0.30	0.27	0.08
	16	1.13	1.96	0.15			
During suckling	2	3.33	3.81	0.34			
	9	1.89	3.62	0.28	0.02	<0.01	0.28
	16	1.54	2.71	0.23			
2-min post-suckling	2	1.77	1.63	0.12			
	9	1.43	1.89	0.14	0.01	0.86	<0.01
	16	1.09	2.42	0.22			
Total	2	6.79	7.44	0.50			
	9	4.55	7.35	0.45	<0.01	<0.01	<0.01
	16	3.76	7.08	0.47			
No. piglets missed suckling bouts[1]	2	0.48 *(0.23)*	0.51 *(0.26)*	0.03			
	9	0.33 *(0.11)*	0.43 *(0.18)*	0.03	0.02	0.02	0.02
	16	0.15 *(0.02)*	0.43 *(0.18)*	0.05			
No. displacements during suckling[1]	2	1.16 (*1.35)*	1.44 *(2.07)*	0.10			
	9	0.64 *(0.41)*	0.97 *(0.94)*	0.08	0.09	<0.01	0.46
	16	0.77 *(0.59)*	0.74 *(0.55)*	0.06			
Proportion of bouts terminated by sow	2	0.48	0.39	0.04			
	9	0.49	0.31	0.04	0.04	<0.01	0.55
	16	0.62	0.48	0.05			

[1]Data square root transformed prior to statistical analysis. Back-transformed means are presented in parentheses.

Table 4. Effects of housing treatment on frequencies of piglet behaviours between 0800 and 1230 h over 3 days of lactation in experiment 1. Data presented as proportion of observations in which the behaviour was observed.

Main effects	Day	Means		SEM	P-value		
		Crates	Pens		Treatment	Day	Treatment x Day
Lying/inactive	2	0.63	0.63	0.01			
	9	0.55	0.54	0.01	0.18	<0.01	0.10
	16	0.57	0.51	0.01			
Walking/standing	2	0.07	0.06	0.00			
	9	0.08	0.07	0.00	0.71	0.19	0.82
	16	0.06	0.07	0.00			
Suckling/udder massage	2	0.24	0.24	0.01			
	9	0.24	0.27	0.01	0.50	0.08	0.34
	16	0.22	0.22	0.01			
Investigatory behaviours							
Pen/floor/sow body	2	0.04	0.03	0.00			
	9	0.05	0.05	0.00	0.62	<0.01	0.62
	16	0.06	0.07	0.00			
Food/water[1]	2	0.01 *(0.00)*	0.02 *(0.00)*	0.01			
	9	0.09 *(0.00)*	0.06 *(0.07)*	0.01	0.66	<0.01	0.32
	16	0.13 *(0.02)*	0.14 *(0.02)*	0.01			
Social behaviours							
Nosing other piglet[1]	2	0.13 *(0.02)*	0.13 *(0.02)*	0.01			
	9	0.16 *(0.03)*	0.17 *(0.03)*	0.01	0.22	0.03	0.77
	16	0.15 *(0.02)*	0.15 *(0.02)*	0.01			
Manipulative behaviour[1]	2	0.05 *(0.00)*	0.03 *(0.00)*	0.01			
	9	0.12 *(0.01)*	0.11 *(0.00)*	0.01	0.05	<0.01	0.94
	16	0.10 *(0.00)*	0.07 *(0.00)*	0.01			
Aggression[1]	2	0.02 *(0.00)*	0.03 *(0.00)*	0.01			
	9	0.15 *(0.02)*	0.14 *(0.02)*	0.01	0.48	<0.01	0.50
	16	0.17 *(0.03)*	0.20 *(0.04)*	0.01			
Mounting[1]	2	0.00 *(0.00)*	0.00 *(0.00)*	0.00			
	9	0.01 *(0.00)*	0.01 *(0.00)*	0.01	0.88	0.26	0.95
	16	0.01 *(0.00)*	0.01 *(0.00)*	0.01			
Play[1]	2	0.04 *(0.00)*	0.05 *(0.00)*	0.01			
	9	0.08 *(0.00)*	0.10 *(0.01)*	0.01	0.05	0.01	0.49
	16	0.07 *(0.00)*	0.10 *(0.01)*	0.01			
Interacting with sow	2	0.01	0.02	0.00			
	9	0.01	0.02	0.00	0.02	0.46	0.71
	16	0.01	0.02	0.00			

[1]Data square root transformed prior to statistical analysis. Back-transformed means are presented in parentheses.

Skin injuries

The majority of both sow and piglet skin injuries assessed in the experimental period were minor scratches (sows on average had 73% scratches, 21% abrasions and piglets on average had 97% scratches). In the piglets, most of these injuries (86%) were on the ears, face, shoulders and neck regions. Sows showed a similar pattern of injuries, with a large proportion (30%) occurring around the face, neck and ears.

As shown in Table 5, the incidence of fresh skin injury for sows was higher in pens than crates (P=0.01), however there was no effect of day (P>0.05) or any effect of a day × treatment interaction (P>0.05). Housing treatment had no effect on the incidence of piglet skin injury (P>0.05) nor was there a significant day x treatment interaction (P>0.05). However, there was a significant effect of day (P<0.01), with more injuries at day 16 compared to day 9.

Table 5 Effects of housing treatment on the incidence of fresh injuries on sows and piglets during the experimental period in experiment 1

Main effects	Day	Means		SEM	P-value		
		Crates	Pens		Treatment	Day	Treatment x Day
Sows	9	0.53 *(0.28)*	1.11 *(1.23)*	0.16	0.01	0.50	0.96
	16	0.65 *(0.43)*	1.25 *(1.57)*	0.17			
Piglets	9	0.73 *(0.53)*	0.65 *(0.42)*	0.11	0.32	<0.01	0.08
	16	1.88 *(3.53)*	2.37 *(5.62)*	0.15			

[1]Data square root transformed prior to statistical analysis. Back-transformed means are presented in parentheses.

Piglet growth rate

There was no treatment effect on piglet weight gain over the experimental period (means (and S.E.M.) were 240 (10.1) and 230 (12.3) g/day for the farrowing crate and lactation pen treatments, respectively, $F_{(1, 30)}$=0.26, P=0.64).

3.2. Experiment 2. Temporary confinement of the lactating sow to day 3 postpartum: effects on pre-weaning piglet welfare and productivity and on sow maternal responsiveness.

PART 1

Behaviour

Piglet behaviour
There were no treatment effects on any of the piglet behaviours studied (Table 7). However, there was a significant day x treatment interaction on the proportion of observations in which piglet interactions with sows ($P<0.01$) and with food/water ($P=0.02$) were observed. More piglet interactions with the sow were observed in the lactation pens at day 9 ($P<0.01$) but not at days 2 ($P=0.06$) and 16 ($P=0.13$). Piglets spent no time interacting with food/water at day 2 in either treatment, and at day 9, the treatments did not differ in time spent interacting with food/water ($P=0.71$). However at day 16 piglets from the lactation pens spent more time interacting with food/water ($P=0.02$).

All of the piglet behaviours studied were affected by time. There was a general reduction in lying behaviour over time ($P>0.01$). Conversely, there was a general increase in the time spent walking ($P<0.01$), investigating the pen ($P<0.01$), nosing other piglets ($P<0.01$) and playing ($P<0.01$) over time. Mounting ($P<0.01$) and aggressive behaviour ($P<0.01$) also showed a general increase over time, although both of these measures peaked at day 9. There was more manipulative behaviour at days 9 and 16 than at day 2 ($P<0.01$), while suckling reduced significantly by day 16 compared with days 2 and 9 ($P<0.01$).

Table 7. Effects of housing treatment on frequencies of piglet behaviours between 0800 and 1230 h over three days of lactation in experiment 2. Data presented as proportion of observations in which the behaviour was observed.

Main effects	Day	Means		SEM	P-value		
		Crates	Pens		Treatment	Day	Treatment x Day
Lying/inactive	2	0.79	0.65	0.02			
	9	0.46	0.43	0.03	0.47	<0.01	0.24
	16	0.54	0.56	0.02			
Walking/standing	2	0.08	0.11	0.01			
	9	0.31	0.27	0.02	0.81	<0.01	0.51
	16	0.35	0.37	0.03			
Suckling/udder	2	0.20	0.22	0.02			
massage	9	0.20	0.19	0.01	0.84	<0.01	0.61
	16	0.11	0.10	0.01			
Investigatory behaviours							
Pen/floor/sow	2	0.05 *(0.00)*	0.10 *(0.01)*	0.01			
body[1]	9	0.22 *(0.05)*	0.20 *(0.04)*	0.01	0.34	<0.01	0.33
	16	0.30 *(0.10)*	0.31 *(0.10)*	0.02			
Food/water[1]	2	0.00 *(0.00)*	0.00 *(0.00)*	0.00			
	9	0.04 *(0.00)*	0.04 *(0.00)*	0.01	0.11	<0.01	0.02
	16	0.03 *(0.00)*	0.08 *(0.01)*	0.01			
Social behaviours							
Nosing other piglet	2	0.00	0.00	0.00			
	9	0.02	0.02	0.00	0.76	<0.01	0.49
	16	0.02	0.03	0.00			
Manipulative	2	0.02 *(0.00)*	0.04 *(0.00)*	0.01			
behaviour[1]	9	0.08 *(0.01)*	0.09 *(0.01)*	0.01	0.37	<0.01	0.83
	16	0.09 *(0.01)*	0.09 *(0.01)*	0.01			
Aggression[1]	2	0.01 *(0.00)*	0.01 *(0.00)*	0.00			
	9	0.16 *(0.03)*	0.14 *(0.02)*	0.01	0.99	<0.01	0.53
	16	0.05 *(0.00)*	0.06 *(0.00)*	0.01			
Mounting[1]	2	0.00 *(0.00)*	0.00 *(0.00)*	0.00			
	9	0.02 *(0.00)*	0.02 *(0.00)*	0.00	0.45	<0.01	0.59
	16	0.00 *(0.00)*	0.00 *(0.00)*	0.00			
Play[1]	2	0.00 *(0.00)*	0.01 *(0.00)*	0.00			
	9	0.06 *(0.00)*	0.05 *(0.00)*	0.01	0.80	<0.01	0.80
	16	0.18 *(0.03)*	0.19 *(0.04)*	0.02			
Interacting with	2	0.03 *(0.00)*	0.02 *(0.00)*	0.00			
sow[1]	9	0.04 *(0.00)*	0.09 *(0.01)*	0.01	0.08	<0.01	<0.01
	16	0.06 *(0.00)*	0.08 *(0.01)*	0.01			

[1]Data square root transformed prior to statistical analysis. Back-transformed means are presented in parentheses.

Maternal responsiveness test

Sows more often in the lactation pens responded to the test by lifting their heads at each approach by the observer at days 9 (P<0.01) and 16 (P<0.01). However, there were no treatment effects on either the occurrence (frequency of tests in which sow grunted) or frequency of grunts (frequency of grunts per test) (P>0.05).

Table 8 Effects of housing treatment on the incidence on behaviour in the maternal responsiveness test during lactation in experiment 2

Main effects	Day	Median		Z-score	P-value
		Crates	Pens		
Number of tests in which sow lifted head (per sow)	9	0.00	2.00	-3.67	0.00
	16	0.00	2.00	-3.61	0.00
Number of tests in which sow grunted (per sow)	9	0.00	0.00	-0.97	0.51
	16	0.00	0.00	-0.55	0.73
Total frequency of grunts over all tests (per sow)	9	0.00	0.00	-0.87	0.54
	16	0.00	0.00	-0.41	0.80

Skin injuries

The majority of both sow and piglet fresh injuries obtained during the lactation period were minor scratches (sows means: 75% scratches and 22% abrasions and piglets means: 75% scratches and 22% abrasions). Most of the piglet injuries (79%) were on the ears, face, shoulder and neck regions. Although sows had injuries in the face, neck and ear regions (18% of injuries), the majority of injuries sustained by sows were on their back and flank (54%) with fewer numbers sustained to the regions of the shoulder (5.0%) and rear (tail, vulva, hock) (5.0%) and the udder (18%). Neither sows nor piglets in either housing treatment were seriously injured during the experimental period.

There was a significant treatment x day interaction for both total (P<0.01) and fresh injuries (P=0.02) in sows (Table 9). While there was no treatment effect on sow total or fresh injuries at day 2 (total, P=0.58; fresh, P=0.81), sows in lactation pens sustained more total (P<0.01) and fresh (P<0.01) injuries at day 9, and more total injuries at day 16 (P=0.04). There was also an overall effect of time on total injuries of sows (P<0.01) but not for fresh injuries (P=0.14). Sows in lactation pens had more total injuries at day 9 (P<0.01) and day 16 (P<0.01) than at day 2 (P=0.54) (Table 9).

Table 9 Effects of housing treatment on the incidence of sow and piglet skin injury during the lactation period in experiment 2

Main effects	Means		SEM	P-Value		
	Crates	Pens		Treatment	Day	Treatment x Day
Numbers of sow injuries						
Total injuries[1]						
Day 2	3.28 *(10.8)*	2.95 *(8.70)*	0.29			
Day 9	3.31 *(11.0)*	4.60 *(21.2)*	0.25	0.41	<0.01	<0.01
Day 16	3.30 *(10.0)*	4.07 *(15.6)*	0.19			
Fresh injuries[1]						
Day 2	1.25 *(1.56)*	1.12 *(1.25)*	0.26			
Day 9	0.66 *(0.44)*	2.29 *(5.24)*	0.25	0.02	0.14	0.02
Day 16	0.65 *(0.42)*	1.08 *(1.17)*	0.18			
Numbers of piglet injuries						
Total injuries						
Day 2	1.53	1.55	0.14			
Day 9	4.05	3.82	0.46	0.04	<0.01	<0.01
Day 16	7.11	13.4	1.24			
Fresh injuries[1]						
Day 2	1.20 *(1.44)*	1.12 *(1.25)*	0.05			
Day 9	1.49 *(2.22)*	1.71 *(2.92)*	0.09	0.11	<0.01	0.08
Day 16	1.85 *(3.42)*	2.37 *(5.61)*	0.12			

[1]Data square root transformed prior to statistical analysis. Back-transformed means are presented in parentheses.

As shown in Table 9, the incidence of total skin injury for piglets was significantly higher in lactation pens compared to crates (P=0.04), and there were significant effects of both time (P<0.01) and a treatment x day interaction (P<0.01). There was an overall increase in total injuries with time, and piglets in lactation pens had more total injuries at day 16 (P<0.01), but not at days 2 (P=0.95) or 9 (P=0.80). There was no treatment effect on the incidence of fresh piglet skin injury (P=0.11) nor was there a treatment x day interaction (P=0.08). However, there was an overall increase in fresh lesions with time (P<0.01) (Table 9).

Piglet growth rate

There were no treatment effects on the daily weight gain of piglets over the experimental period (means (and S.E.M.) of 231.0 (6.73) and 233.0 (11.2) g/day for piglets in the farrowing crate and lactation pen treatments, respectively, $F_{(1,25)}$=0.02, P=0.88).

PART 2

Mortality

There was a tendency for there to be more piglets in the farrowing crates at transfer than in the lactation pens (means for the number of piglets at transfer for sows assigned to lactation pens and to farrowing crates, respectively, were 10.2 and 10.4 piglets, $F_{(1, 659)}$=3.61, P=0.06), and sows in the lactation pens were of a higher parity than those in the farrowing crates (4.15 vs. 3.51 $F_{(1, 669)}$=25.2, P<0.01).

Piglet mortality data, based upon 672 sows that farrowed over 12 months, are presented in Table 10. Average number of dead piglets per litter from day 3 to weaning was not affected by housing treatment (P=0.17), sow parity (P=0.15) or week of farrowing (P=0.29), nor were any of the interaction terms significant (P>0.05).

Table 10. Effect of farrowing crates or lactation pen housing of sows from day 3 of lactation until weaning on piglet mortality (n=672 litters).

	Means		SEM	P-Value
	Crate	Pen		
Sows (n)	332	340		
Parity[1]	3.15	4.15	0.07	<0.001
Litter size at transfer (n)[1,2]	10.4	10.2	0.05	0.06
Piglet mortality (n)[3]	0.64	0.63	0.04	0.17

[1]Analysed using univariate ANOVA.

[2]Data square root transformed prior to statistical analysis. Back-transformed means presented.

[3]Discrete data analysed using a generalised linear model with an underlying poisson distribution. Litter size at transfer was included in the model as a covariate. Raw data are presented

3.3. General Discussion

Behaviour

Suckling behaviour

There were more sow-piglet interactions around suckling in experiment 1 and in total in experiments 1 and 2 in the lactation pens than in conventional farrowing crates. This difference may in part be attributed to piglets having greater accessibility to the sow's head in the lactation pens because of the larger floor space and no restriction imposed by the crate. However, loose-housing of sows during lactation may also have been more conducive to the development and expression of maternal behaviour. Indeed in experiment 2 sows in lactation pens lifted their heads more frequently while feeding in response to a recording of piglet vocalisations.

The importance of sow-piglet nasal contact is demonstrated by its prominence in wild-type compared to domesticated sows and piglets (Gustafsson et al., 1999), suggesting that it is a natural behaviour with some evolutionary advantage. For

instance, sow-piglet interactions may facilitate effective nursing and vertical social learning. Oostindjer et al. (2011a) found piglets learnt to eat solid food from the sow, assisting in the transition to solid feed at weaning. Close nasal contact between sows and piglets may also be important for recognition and communication. This may be particularly important for suckling behaviour, which is regulated by pheromones and olfactory cues detected by piglets (Morrow-Tesch and McGlone, 1990a, 1990b).

The frequency of sow-piglet interaction around suckling and the frequency and duration of suckling bouts declined over time for both treatments. This was expected and is in accordance with parent-offspring conflict theory where weaning occurs gradually as the sow invests less in caring for her young (Bøe, 1993). As shown in experiment 1, however, sow-piglet interactions around suckling decreased at a lesser rate and the overall frequency of sow-piglet interactions increased at a greater rate in the lactation pens than in the crates. Hales et al. (2015c) found that loose-housed sows suckled more frequently in the first 3 days of lactation and bout duration declined at a lesser rate over this period than for confined sows. One explanation of these results is that stronger social bonds form between sows and piglets in lactation pens because of the increased opportunity for sows to express maternal behaviour, and these bond may begin to form very early in life.

In agreement with Gustafsson et al. (1999), experiment 1 found that the number of suckling bouts terminated by sows increased as lactation proceeded. The finding in experiment 1 that sows in crates terminate more suckling bouts, however, contrasts with other findings (Thodberg et al., 2002; Hales et al., 2015c). There is no obvious explanation for these contradictory results except that the present research examined effects following a temporary confinement period of 3 days after farrowing, whereas Hales et al. (2015c) observed housing effects during the first 3 days of lactation. Thodberg et al. (2002) examined suckling behaviour at day 10 of lactation in gilts housed in get-away-pens, which provide significantly more space (7.6m^2 nest area and 6.7m^2 feeding area) than the lactation pens in experiment 1 and allow more voluntary physical separation of the sows from their litters.

The number of piglets missing suckling bouts in experiment 1 was greater at day 16 in lactation pens than in crates. Again, it is not clear why this was the case. The increased area may have allowed for more movement at the udder whereas in the crates, piglets restricted space meant that piglets were not always possible to change teat position after initiation of suckling/massage.

In experiment 2 sows in farrowing crates lifted their heads from feeding less frequently in the maternal responsiveness test than sows in lactation pens. Similar results were been reported by Cronin et al. (1996), although loose-housed sows were housed in pairs. Cronin et al. (1996) also found that sows in crates vocalised less towards their piglets in the maternal responsiveness test, while experiment 2 found no differences between the treatments. Cronin et al. (1996) tested sows at day 3 of lactation, a period where sows in the natural environment would be staying in very close proximity to their litters (Johnson and Marchant-Forde, 2009). On the other hand, in experiment 2 sows were tested at days 12 and 19 of lactation. At this age, under natural conditions, piglets are becoming integrated into the sounder and moving increasingly greater distances from the sow, perhaps corresponding to reduced vigilance from the sow.

Thus, the present research provides evidence of behavioural restriction of either or both sows and piglets in farrowing crates. Housing sows in lactation pens, following a temporary confinement period of 3 days postpartum, appears to increase sow-piglet interactions and thus enhance maternal behaviour. This may be advantageous as the responsiveness of the sow to the piglet's call of distress may reduce the risk of crushing by the sow. However, there is little evidence that increased maternal behaviour leads to improved piglet survival (Cronin et al., 1996).

Maternal behaviour may have been limited in these experiments by the temporary confinement of sows in farrowing crates during parturition and the first 3 days of lactation. Maternal behaviour is regulated by the release of specific hormones, the functioning of which involves complex mechanisms (Algers and Uvnäs-Moberg, 2007) that could be interrupted by behavioural restriction. The prevention of early maternal behavioural expression, particularly nest-building, may have suppressed subsequent maternal behaviour in sows. Limited research suggests that suckling behaviour establishes more easily in litters in which the sow farrowed in pens with straw compared to standard crates (Cronin and Smith, 1992). Nest building behaviour has been associated with reduced incidence of piglet crushing (Andersen et al., 2005; Pedersen et al., 2006). On the other hand, confinement from day 114 of gestation until the birth of the last of the piglets does not affect farrowing progress (Hales et al., 2015a) and may even reduce piglet mortalities (Hales et al., 2015b). Further, Hales et al. (2015c) found that although confinement for 4 days postpartum influenced sow behaviour, this was only minor as little sow activity occurred during this early postpartum period. Indeed sows are inactive for 90-95% of the first 48 hour after farrowing (see Johnson and Marchant-Forde, 2009). The importance of early maternal behaviour on subsequent sow behaviour clearly requires further research.

Piglet social behaviour

Piglets spent more time playing in the lactation pens in experiment 1. It is generally accepted that presence of play behavior is an indicator of positive welfare (see review Held and Špinka, 2011). The increased space in lactation pens may have made it physically easier for play behaviour to be expressed. Alternatively, as found by Chaloupková et al. (2007), enrichment of the pre-weaning environment, through the provision of increased space and thus environmental and social stimulation, may have improved overall piglet welfare and therefore the piglet's motivation to engage in play behaviour.

While play behaviour increased, the prevalence of manipulative behaviour was reduced in lactation pens in experiment 1. Oostindjer et al. (2011b) observed lower levels of belly-nosing and other manipulative behaviours in the 2 weeks post-weaning in piglets of loose-housed lactating sows compared with those housed in crates. High levels of manipulative behaviour, such as belly-nosing, can result in skin injury and ulceration and piglets that express high levels of belly-nosing may also have a reduced growth rate (Straw and Bartlett, 2001). Dybkjær (1992) suggested that manipulative behaviour is a re-directed behaviour and its presence is indicative of a lack of environmental enrichment and/or overcrowding.

In contrast to experiment 1, experiment 2 did not find effects of lactation housing treatment on play or manipulative behaviour. While it is not immediately clear why the results differed between the two experiments, the design of the lactation

pen (e.g., less space in experiment 2) and differences in the behavioural sampling methodology may be responsible. Little is known about the behavioural and physical requirements of piglets during lactation. Social factors, such as individual variation and group dynamics, may also affect the prevalence of positive and negative social behaviours. For instance, Sih (2013) stated that particular individuals (i.e. highly aggressive animals) can have disproportionately large effects on the rest of the group and may even determine the group's dynamics and success. Nonetheless, the results from experiment 1, combined with those reported by others (Chaloupková et al., 2007; Oostindjer et al., 2011b), indicate that play may be increased and manipulative behaviour may be decreased in lactation pens.

Although there were treatment effects on play and manipulative behaviour in experiment 1, there was no treatment effect on nasal contact with other piglets, aggression or mounting in either experiment in the present project. Oostindjer et al. (2011b) similarly found no effect of loose or confined sow-housing on nosing pen-mates, mounting or aggression during lactation. The benefits of improved welfare during lactation may well persist beyond weaning, however. For instance, there is evidence that loose-housing of sows during lactation increases piglet play behaviour post-weaning (Chaloupková et al., 2007; Oostindjer et al., 2011b). Furthermore, Chaloupková et al. (2007) found that piglets reared in lactation pens were less aggressive during a food competition test at 3 and 6 months of age even though post-weaning housing conditions were the same. In contrast, there was no treatment effect on aggression in the 3 hours immediately post-weaning. Maternal behaviour can have marked effects on the development of fear and aggression in offspring (see Curley and Branchi, 2013) and thus further research is recommended to determine whether sow lactation housing effects piglet behaviour after weaning.

There were no treatment effects on investigative or feeding-related behaviours in piglets in experiment 1 of the present project, but in experiment 2, piglets in lactation pens spent more time investigating food at day 16. Oostindjer et al. (2011a) demonstrated a process of vertical social learning in which piglets learned to eat solid food from the sow, showing shorter latencies to eat, greater consumption and preference for the feed containing the same added flavour as was consumed by the sow and piglets during lactation. The feeding system in the lactation pens used in the present body of research, however, did not allow piglets to actively observe the sow eating or to eat from the same container. Duration of observations differed between experiments 1 and 2, but there is no obvious explanation for conflicting results.

It is increasing recognized that particular behaviours may be accompanied by positive or negative emotions (Boissy et al., 2007). For example, play is a rewarding activity and thus is considered to be a marker of positive emotions in animals, while aggression, which can lead to fighting-induced injuries and pain, as well as fear, is considered to be a marker of negative emotions in recipient animals (Hemsworth et al., 2015). As with aggression, manipulative behaviours in piglets, such as nibbling, sucking, chewing or rubbing another piglet, is likely to be a marker of negative emotions in both the piglet displaying the behaviour, since it may be redirected behaviour arising from frustration, as well as the recipient, because of injuries, pain and fear. Clearly, further research is warranted to examine the relationship between sow lactation housing and the prevalence of

these behavioural markers of emotion because of their implications on piglet welfare.

Skin injuries

The interpretation of sow skin injury scores with regard to sow welfare requires some knowledge as to the cause and severity of those injuries. When sows are housed individually, skin injuries may result from contact with pen/crate walls or bars and/or from piglet interactions, such as bites and scratches. Both experiments 1 and 2 found that the majority of the sow injuries obtained were minor scratches and abrasions. The difference in incidence of skin injury between housing treatments may reflect a lack of experience of sows changing posture in the lactation pens, particularly when changing from standing to lying. Industry experience suggests that the plastic flooring used in the lactation pens in the present body of research may be slippery when wet, contributing to difficulties sows may have in changing posture or moving about the pen and consequently may contribute to increased injuries.

Although the majority of injuries were sustained to the sows' sides, the large proportion of injuries present around the sows' faces and necks in both experiments means it is also plausible that the increased interaction with piglets that occurred in the lactation pens contributed to more scratches. Indeed piglets were observed climbing on, playing with and biting sows, particularly around their ears and face. Anecdotal evidence also suggests that there was some aggression between sows in adjacent lactation pens in the present experiments, which may also have contributed to increased injury to the ears and face in this housing treatment.

There were no effects of treatment on fresh piglet skin injuries in either experiments 1 or 2. A majority of piglet injuries were minor scratches and the pattern of injury suggests most were obtained from fighting among pen-mates. This assumption fits with the finding that aggressive behaviour did not differ between treatments (discussed above). However, rough play and collisions with the pen fittings and walls may also result in injuries. While total injuries were not recorded in experiment1, piglets in lactation pens in the second experiment had more total injuries at day 16 than those in farrowing crates. Fresh skin injuries included scratches, abrasions, cuts, and abscesses, while total injuries included fresh injuries as well as partially healed or old injuries. Since total injuries at day 16 provides an assessment of fresh as well as cumulative injuries, further research on skin injuries is recommended because of its implications on the welfare of piglets.

Piglet growth and mortality

There was no treatment effect on piglet growth rate in either experiment in the present project. However, both experiments used focal piglets, balanced for sex and size, to obtain weight gain data. Thus, treatment effects on the extreme (i.e., very small or very large) piglets may not have been apparent with the methodology used in the present project.

Research suggests that piglet mortality increases when sows are loose-housed at farrowing, primarily due to an increase in the incidence of crushing (Blackshaw et al., 1994; de Oliveira Junior et al., 2011; Moustsen et al., 2013; Hales et al., 2014). Around half of total pre-weaning piglet mortalities occur in the first 24 hours of life (Johnson and Marchant-Forde, 2009) and mortalities are highest for the first 3 days postpartum (Moustsen et al., 2013). Danish research has found that temporarily confining sows in crates for 4 days postpartum reduces piglet mortalities for this period (Moustsen et al., 2013; Hales et al., 2015b) although confinement for 7 days postpartum had no additional benefits (Moustsen et al., 2013).

The present research found no difference in piglet mortality between sows that were loose-housed following temporary confinement for 3 days postpartum and those that remained in crates throughout lactation. In contrast to this, Hales et al. (2015b) found that piglet mortality from day 4 of lactation until weaning was lower when sows were loose-housed rather than confined. However, more piglets were crushed when sows were loose-housed in the first four days post-partruition (Hales et al., 2015b). Thus, this present research and the research of Hales et al. (2015b) indicate that piglet mortality in lactation pens is, at the very least, similar to that occurring when sows are confined in farrowing crates, as long as loose-housed sows are temporarily confined for 3-4 days following parturition. No other comparisons of piglet mortality in the period following the transfer of sows to lactation pens until weaning have been made, and thus this topic would benefit from continued research.

Preventing piglet crushing is of obvious importance to both animal welfare and pork production. Johnson and Marchant-Forde (2009) discussed that the design of the farrowing/lactation system can impact piglet survival due to crushing by influencing the behaviour of the sow during posture changes. In particular, the amount of control a sow has over her body in the final stages of moving to a lying position and whether she can roll pose significant risk to piglet crushing. Sows in lactation pens had more fresh and total injuries and piglets in lactation pens had more total injuries. Thus the provision of pen fixtures that not only protect the piglet but assist the sow during postural changes (e.g., piglet protection walls or rails) requires consideration to ensure continued improvement in both injuries in sows and piglets and mortality in piglets when the sow is loose-housed in lactation.

In the present research it was not possible to control or balance for sows that had reared litters in lactation pens previously. Sow experience could potentially contribute to piglet survival and welfare in alternative systems, as has been observed in the trial of a group farrowing system (Wechsler, 1996). Other studies have hypothesised that poor piglet mortality performance in older sows is due to a lack of experience with loose-farrowing housing systems (Hales et al., 2014) and that prior experience with a housing system can affect behaviour early in lactation (Cronin et al., 1996; Weng et al., 2009). The relationship between sow experience and success in such systems is worthy of further investigation.

4. Application of Research

The interpretations from the main research findings are:

1. **Sow-piglet interaction was greater in lactation pens than in farrowing crates, as assessed by actual interaction around suckling and maternal responsiveness to a loud recording of piglet vocalisations.** These findings suggest that maternal behaviour of sows in farrowing crates is restricted. Increased maternal behaviour of sows may improve piglet welfare by reducing risk of overlaying and sow welfare in the short-term by reducing frustration associated with not being able to perform highly motivated maternal behaviours. However, increasing maternal interactions may also have short and long-term positive effects on piglet welfare and productivity in terms of social learning and development, and reducing fear response and aggression. These early influences may consequently improve piglet productivity by reducing stress and injury at weaning, and thus improving rates of growth and feed conversion. The long-term effects of increased maternal behaviour of sows on piglets require further investigation.
2. **There were no housing effects on piglet aggressive behaviour, but in one of the two experiments, piglet play was increased and piglet manipulative behaviour, such as such as sucking and chewing other piglets, was reduced in lactation pens.** These inconsistent results highlight how little is known about the behavioural and physical requirements of piglets during lactation. The increased space in lactation pens in experiment 1 may have made it physically easier for play behaviour to be expressed and further research the effects of floor space on play and manipulative behaviour is required. In addition to the design of the pen, piglet behaviour may be influenced by the social environment, such as the behaviour of litter-mates. While research is limited, evidence suggests, including the present research, that piglet welfare is generally enhanced in lactation pens as positive social behaviours, such as play behaviour and sow-piglet interactions increase, and harmful behaviours, such as manipulation of other piglets, reduce.
3. **Piglets sustained more total skin injuries in the lactation pens, but there were no housing effects on piglet fresh injuries. Sows in lactation pens sustained more total and fresh injuries. The majority of sow and piglet injuries were minor.** The proportion of skin injuries that were present around the sows' faces and necks suggest that increased interaction with piglets in the lactation pens contributed to more scratches for sows in this treatment. Nonetheless, the majority of sow and piglet injuries in both treatments were minor and thus their significance for welfare is uncertain.
4. **Temporarily confinement of the lactating sow to three days post-farrowing did not increase piglet mortality or reduce piglet growth.** The combined results of the present and two Danish studies indicate that housing sows in lactation pens following temporary confinement at the beginning of lactation does not increase piglet mortality. Changes to the design of the lactation pen such as the provision of pen fixtures that not only protect the piglet but assist the sow during postural changes (e.g., piglet protection walls or rails) require consideration in order to safeguard piglets in lactation pens. Further, sow experience with a housing system

could make a significant difference to piglet survival and thus the experience of the sow with the housing system should be considered when reviewing research and industry data on new loose housing systems for parturient and lactating sows.

5. Conclusion

The present research, comprising two experiments, suggests that, following temporary confinement in a farrowing crate, increased floor space and greater opportunity for interaction between sows and piglets from days 3 to 28 of lactation may result in improved maternal behaviour in sows and improved social behaviour in piglets, such as increased play and reduced manipulative behaviours such as sucking and chewing other piglets. Piglet mortality was not affected by housing sows in lactation pens following temporary confinement from day 110 of gestation to day 3 of lactation.

While these results suggest an improvement in piglet welfare in the loose pens from day 3 of lactation, clearly further and more extensive observations on piglet behaviour, both pre- and post- weaning, and maternal behaviour are required. Examination of the long-term effects on post-weaning piglet social behaviour and performance is required because of the potentially important early experiential effects. The lack of treatment effects on the social behaviour of piglets in experiment 2 may be due to the slightly smaller lactation pens in the experiment (4.2 vs. 4.5 m^2 in experiment 1) and this also clearly warrants further study. A better understanding of the effects of design features and their location in the pen to protect piglets and assist sows when changing posture, particularly near vertical structures, may ensure amelioration of both injuries in sows and piglets and mortality in piglets. Comparisons of piglet injuries and mortality in the period following the transfer of sows to lactation pens until weaning and piglet behaviour before and after weaning are limited, but results to date indicate that further research on these topics may lead to significant opportunities to safeguard piglet welfare.

The present findings and recent overseas research indicate that housing sows and their litters in lactation pens following temporary confinement in a farrowing crate early in lactation when the risk of piglet mortality is high, offers an opportunity to minimise piglet mortality while reducing welfare risks to both sows and their piglets. For those producers that are interested but hesitant in transitioning to a totally confinement-free system, temporary confinement early post-partum appears to provide an intermediary step that offers an overall improvement in both sow and piglet welfare before transitioning to a totally confinement-free system.

6. Limitations/Risks

The main limitation that should be considered when interpreting the results of this project is that they are particularly applicable to the management procedures and housing systems described in the methodology. These results may, or may not, be directly applicable to different lactation pen designs (i.e. bedding, space, and other pen and creep design features) and genetic strains (which could affect

maternal behaviour). Further, the management requirements for pigs housed in lactation pens are likely to be greater than for those housed in farrowing crates, particularly in terms of increased surveillance and intervention. Consequently, the application of the results of this project to other industry settings may depend increasingly on the training and competency of production staff.

7. Recommendations

As a result of the present findings and recent overseas research, the following recommendations are made:

- A comprehensive investigation into the effects of housing sows and litters in pens from early lactation on sow maternal behaviour and welfare during lactation and piglet social behaviour and welfare, both pre- and post-weaning, as well as piglet pre-weaning and post-weaning growth performance.
- Consideration of the design of the lactation pen should include total floor space for both sows and piglets and provision of pen fixtures that not only protect the piglet but assist the sow during postural changes (e.g., piglet protection walls or rails).

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