

The welfare of gestating sows in conventional stalls and large groups on deep litter

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Accepted 15 May 2006

Available online 1 August 2006

Abstract

Confinement of breeding sows and gilts is a controversial welfare issue in livestock production and there is worldwide interest in finding alternative housing systems for gestating pigs. This study measured aspects of the welfare of gestating sows housed in either large groups on deep litter (Hoops) or conventional stalls (Stalls). Six hundred and forty sows were studied, with 40 recently mated sows weekly entering each treatment over an 8-week period; groups of 85 were formed using 40 experimental and 45 non-experimental animals. Sows in Hoops had a higher ($P < 0.001$) number of scratches, a higher ($P < 0.01$) return rate to oestrus after mating (13.20% versus 7.35%) and there was a trend ($P = 0.06$) for higher salivary cortisol concentrations in week 1 of gestation (6.29 nM versus 4.03 nM). Sows in Stalls had a higher incidence of lameness at weeks 9 and 15 of gestation (13.8% versus 0.8% at week 15) ($P < 0.01$). There were changes in some leucocyte sub-populations in the Stalls treatment late in gestation: the percentage of neutrophils was higher (46% versus 41% of WBC), the number and percentage of lymphocytes was lower (4.59×10^6 c/mL versus 5.16×10^6 c/mL and 41.6% versus 46.5% of WBC) and consequently there was a higher neutrophil:lymphocyte ratio (1.22 versus 0.94) ($P < 0.05$). There was a trend ($P = 0.06$) for a lower reproductive failure in the Stalls treatment (14.5% versus 27.3%); farrowing rate was higher (76.8% versus 66%), and while sows in Stalls weaned fewer piglets per litter (8.31 versus 8.97), the average weaning weight of these piglets was higher (8.69 kg versus 8.01 kg) ($P < 0.01$). The combination of these reproductive parameters resulted in sows in the Stall treatment weaning the equivalent of 39 more piglets

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per 100 mated sows. The results suggest that sows in large groups on deep litter faced greater welfare challenges in the early stages of gestation based on the findings of increased scratches, a higher rate of return to oestrous and a trend for higher cortisol concentrations early in gestation, all possibly a consequence of aggression. In contrast sows in stalls faced greater welfare challenges later in gestation based on a higher incidence of lameness and an increased neutrophil:lymphocyte ratio perhaps as a consequence of increased stress. In conclusion, these data suggest that in both housing systems the welfare advantages and disadvantages change overtime.

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Keywords: Sow; Welfare; Housing; Aggression; Stress; Reproduction

1. Introduction

Confinement of breeding sows and gilts is one of the most controversial issues in livestock production, together with floor space allowance and lack of bedding (Barnett et al., 2001). However, consideration of the welfare implications of group versus stall housing during gestation is complex. Both housing systems have some clear advantages and disadvantages in relation to pig welfare. For example, individual housing in stalls restricts the sows' opportunities to exercise, socially interact and interact with other features of the environment, but on the other hand, group housing raises welfare issues concerning space allowance and level of aggression.

About 70% of the breeding sows are kept in stalls during gestation (Barnett et al., 2001). The ongoing welfare debate about stall housing has led to the examination of alternative housing systems for breeding sows. There is little information in the scientific literature on the welfare of gestating sows in groups of more than 40 animals and there is no scientific literature on housing breeding sows or gilts in large groups on deep litter. The present experiment was conducted to compare the welfare and reproductive performance of gestating sows when housed in conventional stalls with that of gestating sows housed in large groups on deep litter. The basis of the approach to assess sow welfare in this study was that difficult or inadequate adaptation will generate welfare problems for animals (Broom and Johnson, 1993; Barnett and Hemsworth, 2003) and thus a broad examination of the behavioural, physiological, health and fitness responses of sows under these two housing treatments was undertaken to assess biological functioning of the animals.

2. Materials and methods

This experiment was conducted in two adjacent units of a large commercial piggery in Corowa, New South Wales, Australia and commenced in October (2002) and concluded in April (2003) (spring and summer seasons in the southern hemisphere). Due to the large number of animals studied and the construction of the two housing systems, it was not possible to house the two treatments in one location, however all experimental animals farrowed in the same farrowing building to avoid bias in the productivity data. The two gestation houses were located approximately 2 km apart, in buildings with similar orientation and the batches of sows were randomly allocated to accommodation to each site location site location.

2.1. Animals

Six hundred and forty sows of good health at the beginning of the study were used. Once a week over 8 weeks, two groups of 40 crossbred sows (Landrace × Large White) were randomly selected at weaning and

housed in individual stalls to be artificially inseminated. After each sow received two artificial inseminations, each of the two groups in each of the 8 weeks was introduced to their gestation treatment, conventional stalls (“Stalls”) or large groups in a deep litter system with external feeding stalls (“Hoops”). All sows had spent the previous gestation in the same housing treatment they were allocated to for this experiment. Prior to the previous gestation, sows of parity 2 and older had spent their gestation in stall housing.

The major measurements in the experiment were conducted on 18 focal sows in each of the 8 replicates of each treatment. The focal groups included sub-groups of sows of parity one, parity two and parity three or more, in a proportion of approximately 1:1:1, respectively. For identification purposes all animals were tattooed and tagged, and the focal sows were marked on the back and the sides with spray paint using three different colours to identify the parity sub-group. Sub-groups were re-marked the day before each observation day.

2.2. Housing treatments

The sows in the Hoops treatment were housed in pens of 9 m × 22.5 m ($w \times l$) on 30 cm deep rice hull bedding. There were 16 pens in total, located back to back in pairs, and each pair of pens was located in one building. Each building consisted of a galvanised ark shaped frame with polyethylene (Canvacon 5000[®]) roof. All sheds had blinds on the sides to regulate temperature and ventilation. Floors were concrete and walls were made of recycled conveyer belts from the mining industry. Supplementary non-experimental, recently inseminated sows were added to complete a group of approximately 85 sows in each pen, which provided a floor space of 2.3 m² per sow. The rice hulls were put on the concrete floor in piles allowing the sows to spread it within the shed. Water was provided in troughs within the pen, although two of the replicates had swinging nipple drinkers suspended from an overhead frame. Sows were moved into their pen in two batches over 2 days and remained in the group until 1 week prior to the expected farrowing date. Farm staff carried out regular oestrus checks during the first 5 weeks post-mating and sows were then checked for pregnancy using ultrasonography.

The groups of sows in the Stalls treatment were in a farm unit together with non-experimental stall-housed breeding sows. The farm unit was divided into 24 batches of approximately 215 stalls. After artificial insemination, the sows were moved to a different part of the same shed for the following 4 weeks. During this period, farm staff carried out regular oestrous checks. After a pregnancy test by ultrasonography in the fifth week of gestation, the pregnant sows were moved to another shed where they were housed initially until the week before their expected farrowing date. Stalls were 0.6 m × 2.1 m in size ($w \times l$) including the trough, had a partially slatted concrete floor (50%) and had stall sides constructed of three horizontal bars per side.

Both treatments were provided with water sprayers for thermoregulation on hot days. All sows that returned to oestrus and those that tested negative at the pregnancy test were recorded and culled from the experiment. The week before the expected farrowing date all sows were transported by truck to the same farrowing facility, which consisted of 5 rooms, each containing 64 farrowing crates (four rows of 16 crates). The crates had a fixed bar (top) and a mobile bar (bottom) and the entire floor was metal slats. The dimensions of the crates were 0.60 m on the top and the bottom bar allowed a maximum width of 0.90 cm. This crate was located in the centre of a square pen of 2.1 m per side. Each crate had a feed trough and a nipple drinker. Each replicate of both treatments was allocated to one room of the same farrowing house every week.

2.3. Feeding

All experimental sows were fed daily around 07:30 h with a commercial diet (13.1 MJ/kg DM, and 12.8% protein) and sows in both treatments received 2.5 kg/day of this diet. Each group of the Hoops treatment was daily released from their pen to be fed in a central feeding station located 40–60 m away from their accommodation pen. The feeding station consisted of a partially walled shed with two batches of 50 stalls separated by a central corridor. Feed was delivered before the sows were released from the pens. The stalls accommodated the full length of the sow. The layout of this feeding station is shown in Fig. 1. Each

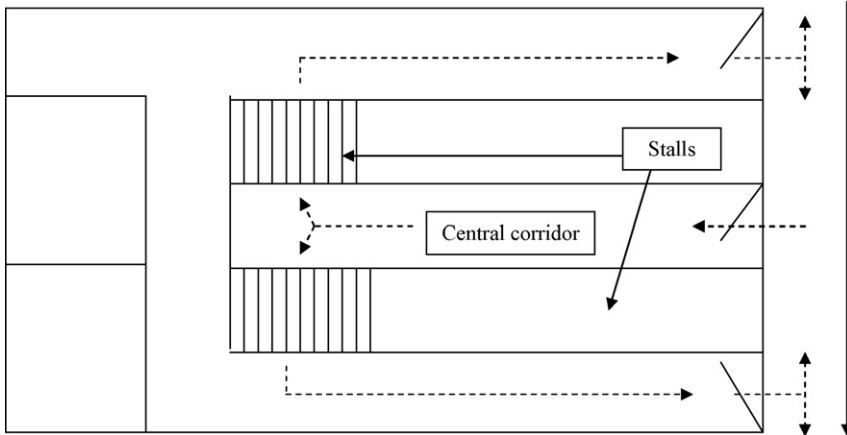


Fig. 1. Stall feeding station used for the sows housed in Hoops. The dotted arrow indicates movement of animals to and from the feeding stalls.

sow entered a feeding stall through the rear via a central corridor and was locked in the feeding stall for about 20 min daily for feeding. Sows exited the stall through a manually operated front gate. The stalls had a concrete trough 0.20 m across \times 0.15 m high, which transversed the width of the stall.

2.4. Skin injuries and locomotion

A modification of the assessment described by de Koning (1993) was used to describe skin lesions in both treatments. The assessment was simplified for the present experiment by reducing the number of areas in which the body of the sow was divided for injury data collection. Fresh skin lesions were classified as scratches, abrasions and skin ulcers and cuts. Each side of the sow's body was divided into 21 areas as shown in Fig. 2 and described as follows: face (1), ear (2), neck (3), throat (4), processi scapulae (5), elbow (6), carpus (7), fetlock (8), coronary edge of the foreleg (9), hoof of the foreleg (10), sole of the foreleg (11), accessory digits of the foreleg (12), back and flank (13), tail and vulva (14), stifle (15), hock (16), coronary edge of the back leg (17), hoof of the back leg (18), sole of the back leg (19), accessory digits of the back leg (20) and udder (21). The number and the type of skin lesions were recorded pre-mating and in weeks 1, 9 and 15 of gestation.

Locomotion was assessed in both treatments by examining the legs of the sow while standing, walking and trotting. These assessments were conducted by two experimenters. The sows from the Stall treatment were allowed to walk freely for at least 30 m before the assessment to avoid confusion between stiffness, as a product of the lack of exercise and a low degree of lameness. All focal sows were forced to walk and trot for at least 50 m along a concrete walkway. However, sows that were severely lame were not forced to trot to avoid further injury. One experimenter stood behind the sow to encourage movement by placing his hand on the back of the sow and giving gentle slaps when necessary. The second experimenter observed the sow from the front and the back to identify any sign of lameness. A four-point scale was used to assess lameness and sows were scored as follows. A score of 0 was given to animals judged to be sound on the basis that it appeared their ability to stand and move was not affected and their limb movements were symmetrical. A score of 1 was given to animals that were not considered lame in that it appeared their ability to stand and move was unaffected and all their legs were able to bear weight similarly, but their movement was compromised. A score of 2 was given to animals judged to be moderately lame on the basis that it appeared their ability to stand was obviously reduced. Furthermore, it appeared that movement by these animals was diminished and difficult, and that the animals refused to put weight on the affected leg/s and if more than one limb was affected, sows may frequently lift and replace one or two feet from the ground. Severely lame animals, which received a score of 3, were assessed on the basis that it appeared that their ability to stand and

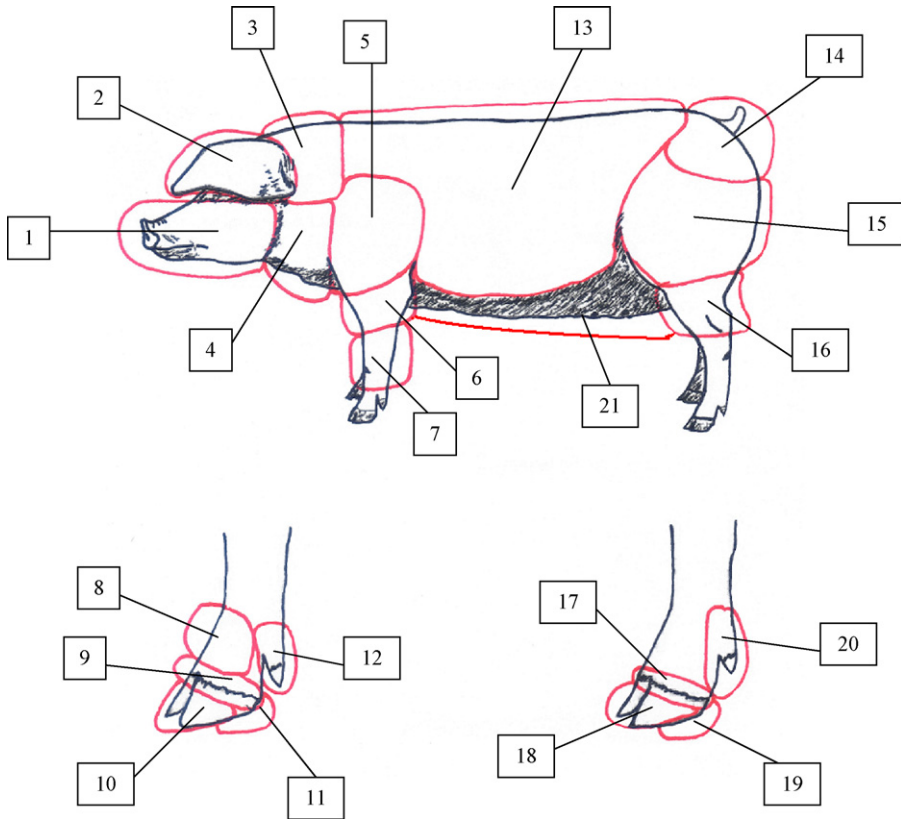


Fig. 2. Divisions of the surface of the sow where injuries were assessed.

move was very restricted. These animals were unable to put weight on one or more legs and often swollen joints, stiffness and frequent vocalisations (squealing) were observed if they were moved. The incidence of lameness was assessed at weaning and on weeks 9 and 15 of gestation.

2.5. Behaviour

Observations on the time budget of behaviour were conducted on both treatments in weeks 1 and 9 of gestation and were conducted on the two treatments in each replicate on consecutive days in the weeks of observation. These observations consisted of observing each focal sow every 5 min for 40 min. Observations on sows in the Hoops treatment were conducted from outside the pen, half way along the long side of the pen, on a 1 m tall platform to facilitate observations. The observer scanned the pen from left to right and recorded what each of the focal sows was doing at the particular moment the observer had visual contact with the sow. A similar procedure was used in the Stall treatment, except the observer was located in the aisle central to the study animals. The observer recorded whether the sow was lying, sitting or erect (standing or walking), drinking, manipulating objects (features of the pen, stalls, stones, sticks, etc.), interacting with the floor (including bedding) or other pigs (social or aggressive behaviour) and repetitive movement of the jaws with increased salivation (champing). In the Hoops treatment only, these observations were followed by 10 min of continuous observation to record the number of aggressive interactions in which, at least one focal sow was involved. An aggressive interaction was recorded when a focal sow was either attacked or retaliated and behaviours recorded included bites, head knocks and sustained fighting. This procedure (scanning and continuous observation) was repeated four times between 09:00 and 13:00 h on weeks 1 and 9 of gestation.

A small number of experimental sows was observed 2 days after entering the farrowing crate to assess fear response to humans. Twenty-five sows from each treatment were randomly selected and studied in the test used by [Hemsworth et al. \(1981, 1989, 1999\)](#). One experimenter approached the sow from the back and slapped the sow twice on the back to ensure that it was standing. Standing sows were also slapped to provide all sows with the same level of human contact before the observation and sows received patting following testing. A small amount of feed in a novel plastic tray was offered to the sow before their normal feeding time and was placed on the floor by a second experimenter, who withdrew about 2 m down the corridor away from the sow. After 5 s of feeding the experimenter slowly approached the sow and placed his hand about 5 cm away from the snout of the sow for 30 s. The test commenced when the hand of the experimenter was close to the sow and observations were taken on whether or not the sow withdrew from the novel feed tray, the time taken by the sow to return to the feed tray and the time spent by the sow within 5 cm of the food.

2.6. Cortisol concentrations

To determine the effects of sampling different animals within a group over time, a preliminary study on non-experimental animals was conducted to determine whether repeated sampling of saliva and/or the presence of humans in the pen affected subsequent saliva cortisol concentrations. From each of three groups of 85 sows, six sows were sampled as follows. The first group of six was sampled at 0, 5, 10, 15, 20, 25 and 30 min; the second group at 0, 15 and 30 min and the last at 0 and 30 min to examine effects of previous sampling on cortisol concentrations. Samples obtained at 0, 15 and 30 min were analysed.

In the main experiment, saliva samples were collected from the 18 focal animals selected in each treatment in each of the 8 replicates on day 5 and during week 9 of treatment. Saliva samples were collected between 13:00 and 14:00 h. Samples within parity ages (1, 2 and 3 and older) within weekly batches (replicates) were collected for each treatment and analysed for cortisol concentrations.

Saliva samples were collected using cotton plugs (Salivettes[®], Sarstedt Australia, South Australia, Australia). Each focal sow was allowed to chew on the Salivette[®] for approximately 30 s. All the samples were collected as quickly as possible, starting at 13:00 h the day of the observation in each treatment. Collection time for each sample was also recorded. A maximum of 3 min was allowed to obtain the saliva sample. When it was not possible to obtain the sample in that time period, the sow was left alone and another attempt was carried out when all the other samples had been collected. Samples were centrifuged at 7000 rpm and stored frozen at -20°C until analysed. Salivary cortisol concentration was measured using a commercial assay kit (Orion[®] kit, Australian Lab Services).

2.7. Haematology and immune competence

Blood samples were taken at week 15 of gestation by venipuncture of the jugular vein. The samples were taken once the sows had spent 3 days in the farrowing crate. A 6 mL sample was taken in a heparinised tube (Vacutainer[®] Beckton, Dickinson and Co., NJ, USA). Haematology, lymphocyte proliferation and lymphocyte phenotype was analysed from this sample. Haematology assays were conducted using Cell Dyne 3700[®] counter (Abbot Diagnostics, Lane Cove NSW, Australia). Immune competence assays were conducted by measuring lymphocyte proliferation after mitogen stimulation. Proliferation technique was used as described by [Snider III et al. \(1986\)](#) with some modifications. Assays were conducted using phytohaemagglutinine (PHA, Wellcome, Dartford, UK) in two dilutions (50 and 10 $\mu\text{g}/\text{mL}$) and unstimulated for medium only control. The dilutions were incubated for 24 h, and read in a β -counter with scintillant. Results were expressed as a stimulation index.

2.8. Reproductive performance

All the sows farrowed in a common farrowing environment. The reproductive performance data collected allowed the following aspects to be calculated: farrowing rate, litter size (total born, born alive,

stillborn, mummified piglets) and litter weight (litter weight at birth, average piglet weight at birth, litter weight at weaning and average piglet weight at weaning). Data on returns to oestrus, NIPs (“not-in-pig sows”, that is, sows confirmed pregnant but failed to farrow), uro-genital infectious discharges and abortions were also collected.

2.9. Statistical analysis

Unless otherwise mentioned, all data were analysed by analysis of variance using the Genstat statistical package. The group was the experimental unit for comparisons between treatments. The model included starting week as a blocking factor. Treatment was tested using replicate \times treatment as the error. When comparisons were made among sow parity levels, this was analysed as a sub-plot within group, using parity level means within group as the experimental unit. When variables were assessed at more than one point during gestation, separate analyses were conducted within each stage of gestation. Residuals were examined following a preliminary analysis using raw values, and if necessary to meet the variance criteria for an analysis of variance, data were transformed prior to a second analysis. This resulted in injury data being square root transformed, and behaviour data being \log_{10} transformed. Lameness scores obtained during the previous lactation were used a covariate for subsequent lameness scores. Conception, farrowing and culling rates, as well as the number of sows with lameness scores of 2 or higher, were tested by Chi-square.

3. Results

3.1. Injuries and locomotion

The incidence of scratches was lower ($P < 0.0001$) in the Stall treatment throughout gestation, although the number of scratches in the Hoops treatment decreased substantially in middle and late gestation (Table 1). Most scratches probably originated from aggressive interactions in both treatments. In contrast, the incidence of abrasions was significantly higher ($P < 0.0001$) in the Stall treatment than in the Hoops treatment (0.91 abrasions/sow versus 0.01 abrasions/sow). Although the incidence of abrasions was not very high, it was apparent that older sows particularly in early gestation were the ones with multiple abrasions. Abrasions were located mainly on the back (back sores) and accessory toes of the hind legs. Incidence of abrasions was negligible in the Hoops treatment at weeks 9 and 15. No treatment differences were found in incidence of cuts ($P > 0.05$; Table 1).

Table 1
Effect of housing treatments on incidence of injuries (means \pm SED presented)

Measurement	Stall	Hoops	SED
Number of scratches at			
Weaning	0.8	0.1	0.230
Week 1 of gestation	3.3 ^a	25.0 ^b	0.162
Week 9 of gestation	2.0 ^a	8.6 ^b	0.464
Week 15 of gestation	1.1 ^a	7.6 ^b	0.505
Number of abrasions at			
Weaning	1.6	1.3	0.104
Weeks 1 to 15 weeks of gestation	0.91 ^a	0.01 ^b	0.056
Number of cuts at			
Weaning	0.5	0.4	0.111
Weeks 1 to 15 weeks of gestation	0.15	0.10	0.061

Within rows, significant differences are indicated by different superscripts; ^{a,b} $P < 0.0001$.

Table 2

Effects of housing treatment on locomotion scores (means \pm SED presented; means adjusted for covariate)

Measurement	Stall	Hoops	SED
Locomotion score at week 9	0.711 ^a	0.156 ^b	0.100
Locomotion score at week 15	0.645 ^a	0.174 ^b	0.085

Within rows, significant differences are indicated by different superscripts; ^{a,b} $P = 0.001$.*Note:* Locomotion score at weaning previous to treatment used as covariate.

Table 3

Effect of housing treatment on percentage of sows with lameness scores of 2 or more (means presented)

Measurement	Stall	Hoops	χ^2_1
Percentage of sows scoring 2 or 3 at week 9	7 ^a	0 ^b	9.333
Percentage of sows scoring 2 or 3 at week 15	13.8 ^c	0.8 ^d	14.960

Within rows, significant differences are indicated by different superscripts; ^{a,b} $P < 0.01$; ^{c,d} $P < 0.001$.

The locomotion score was higher ($P = 0.001$) in the Stall treatment (Table 2), reflecting more severe locomotion problems amongst the sows housed in Stalls. The percentage of affected animals scoring 2 or more was higher ($P < 0.001$ and $P < 0.001$ for weeks 9 and 15, respectively) in the Stall treatment than those in the Hoops treatment (Table 3).

3.2. Behaviour

In both treatments the sows spent most of their time lying and there were no treatment effects on the percentage of observation bouts that the focal sows were lying or erect (standing or walking) at week 1 of gestation ($P > 0.05$; Table 4). The time spent lying increased between weeks 1 and 9 of gestation in both treatments. However the increase was significantly higher ($P < 0.01$) only in the Stall treatment. The time spent lying was greater ($P < 0.005$) in the Stall

Table 4

Effects of housing treatment on behaviour at weeks 1 and 9 of gestation (percentage of observation bouts (\pm SED presented) in which each behaviour was observed)

Measurement	Stalls	Hoops	SED
Lying at week 1	74	76	3.3
Lying at week 9	86 ^a	79 ^b	1.5
Erect at week 1	23	23	2.9
Erect at week 9	11 ^a	19 ^b	1.8
Sitting at week 1	2.8 ^a	0.8 ^b	0.185
Sitting at week 9	2.0	1.4	0.332
Drinking at week 1	3.8	3.0	0.060
Drinking at week 9	1.0	2.0	0.085
Pig interactions at week 1	0.5	1.0	0.060
Pig interactions at week 9	0.4	0.8	0.051
Floor interactions at week 1	2.2 ^c	5.9 ^d	0.049
Floor interactions at week 9	1.1	3.3	0.155
Object interaction at week 1	5.5 ^e	2.3 ^f	0.092
Object interaction at week 9	1.8	0.6	0.111

Within rows, significant differences are indicated by different superscripts; ^{a,b} $P < 0.005$; ^{c,d} $P < 0.0005$; ^{e,f} $P < 0.05$.

treatment at week 9 and the time spent erect (standing or walking) was less ($P < 0.005$) in the Stall treatment at week 9 of gestation. There were no parity effects on lying or erect. Sows in the Stall treatment spent a higher percentage ($P < 0.005$) of time sitting than the sows in Hoops treatment in week 1 of gestation (Table 4), however the difference was not significant by week 9 of gestation ($P > 0.05$). Sows in the Stall treatment had more ($P < 0.05$) interactions with objects (particularly bar and trough biting, licking and nosing) in week 1 of gestation and there was a strong tendency ($P = 0.06$) in the same direction in week 9, compared to sows in the Hoops treatment. In contrast, the percentage of time spent interacting with the floor was higher ($P < 0.001$) in the Hoops treatment than in the Stall treatment at week 1 of gestation. Interactions between pigs tended to be higher ($P = 0.06$) in the Stall treatment both at weeks 1 and 9 of gestation. Champing was only observed in the Stall treatment (5.54% and 2.86% of observation bouts, for weeks 1 and 9 of gestation, respectively). Time observed champing was slightly higher ($P = 0.07$) in older sows (4%, 6% and 6% at week 1 of gestation and 3%, 2% and 4% at week 9 of gestation for parities 1, 2 and 3 and over, respectively). No significant difference between treatments was found in the time spent drinking, however there was a tendency for this to be higher ($P = 0.08$) in the Hoops treatment at week 9 of gestation (Table 4).

There was a significant ($P < 0.05$) reduction in the number of aggressive interactions within the Hoops treatment from weeks 1 to 9 of gestation. An average of 1.3 aggressive interactions per group per observation bout was observed at week 1, while at week 9 the average number of aggressive interactions was 0.5 per observation bout (SED = 0.223). Furthermore, the nature of the aggression changed between weeks 1 and 9 of gestation. While at week 1 sows engaged in vigorous fighting, by week 9 aggression was reduced mostly to head knocks, single bites and charges by dominant animals and avoidance behaviour by submissive ones.

The fear response test showed several treatment effects (Table 5). Although there was no difference in the initial approach to the feed tray ($P > 0.05$), a higher ($P < 0.01$) percentage of sows from Stalls withdrew on the approach of the experimenter. In addition, sows from the Stall treatment were slower ($P < 0.001$) to return to the feeding tray in the presence of the experimenter, and therefore, spent less ($P < 0.05$) time near the feeding tray than sows in the Hoops treatment (Table 5).

3.3. Cortisol concentrations

The results of the pre-study assessment of the effects of previous sampling showed no significant differences in salivary cortisol concentrations taken at 0, 15 and 30 min. In the main experiment, most attempts to collect saliva were successful in less than 3 min and therefore, very few sows had to be approached twice (seven sows only). There were no treatments effects on salivary cortisol concentrations at either week 1 or 9, although there was a strong tendency ($P = 0.06$) for higher cortisol concentrations in the Hoops treatment than in the Stall treatment at

Table 5
Effects of housing on the fear response of sows to humans (mean \pm SED presented)

Measurement	Stall	Hoops	χ^2_1 or SED*
Initial feeding (%)	73	84	0.86
Withdrawal (%)	64 ^b	24 ^a	7.52
Return after withdrawal (s)	13.4 ^d	1.4 ^c	2.93*
Total feeding time (s)	16.6 ^f	24.0 ^e	3.66*

Within rows, significant differences are indicated by different superscripts; ^{a,b} $P = 0.005$; ^{c,d} $P < 0.001$; ^{e,f} $P < 0.05$.

week 1 (6.29 nM versus 4.03 nM, SED = 1.037). Concentrations at week 9 were 3.81 and 4.02 nM for sows in the Stall and Hoops treatments, respectively (SED = 0.304).

3.4. Haematology and immune competence

In both treatments all the values for the different type of cells were within physiological ranges (Table 6). However, the absolute value of lymphocytes was significantly ($P < 0.05$) lower in sows in the Stalls. There were no significant treatment differences in the other absolute values, however, the number of neutrophils tended to be higher ($P = 0.08$) in the Stall treatment. Significant ($P < 0.05$) treatment differences were found in the percentages of both neutrophils and lymphocytes (Table 6). Percentage of neutrophils was higher and percentage of lymphocytes was lower in sows in the Stall treatment than in the Hoops treatment. As a consequence, the ratio between neutrophils and lymphocytes was significantly higher ($P < 0.05$) in the Stall treatment.

Lymphocyte proliferation was an 11.1% (50 $\mu\text{g/mL}$ of PHA) and 14.5% higher (10 $\mu\text{g/mL}$ of PHA) in the Hoops treatment, however these results were not significant ($P > 0.05$). No significant treatment effects were found in the different lymphocyte sub-populations or in the red blood cell count.

3.5. Reproductive performance and productivity

The farrowing rate was higher ($P < 0.001$) in sows from Stalls than in sows from the Hoops treatment (76.9% versus 66.0%, respectively; $\chi^2_1 = 26.218$). There was no parity effect on farrowing rate. There was a strong tendency ($P = 0.06$) for reproductive failure to be higher in the Hoops treatment than in the Stall treatment (27.3% versus 14.5%; $\chi^2_1 = 3.265$), mainly due to a higher ($P < 0.05$) incidence of regular and irregular return to oestrus in the Hoops treatment (13.2% versus 7.35%, for Hoops and Stall treatments, respectively, $\chi^2_1 = 4.659$). Other reproductive failures, such as abortions and urogenital tract infections, were only recorded in the Stall treatment (<1% and 2.4%, respectively). Productivity values are presented in Table 7. The number of weaned piglets per farrowed sow was lower ($P < 0.01$) in the Stall than in the Hoops treatment. In contrast, the average piglet weight was higher ($P < 0.005$) in the Stall than in the Hoops, however, piglets from sows in the Hoops treatment had on average 2 days less of

Table 6
Effects of housing treatments on haematology (means and SED presented)

Measurement	Stalls	Hoops	SED
WBC (10^6 c/mL)	11.22	11.19	0.296
Neutrophil (10^6 c/mL)	5.26	4.66	0.285
Neutrophil (% of WBC)	46.0 ^a	41.0 ^b	2.090
Lymphocytes (10^6 c/mL)	4.59 ^a	5.16 ^b	0.223
Lymphocytes (of WBC %)	41.62 ^a	46.45 ^b	1.833
Neu/Lymph ratio	1.22 ^a	0.939 ^b	0.111
Eosinophils (10^6 c/mL)	0.728	0.719	0.133
Eosinophils (% of WBC)	6.81	6.71	1.145
Monocytes (10^6 c/mL)	0.555	0.568	0.043
Monocytes (% of WBC)	0.724	0.783	0.048
Basophils (10^6 c/mL)	0.082	0.086	0.006
Basophils (% of WBC)	0.724	0.763	0.048

Within rows, significant differences are indicated by different superscripts; ^{a,b} $P < 0.05$.

Table 7
Effects of housing on productivity (means and SED presented)

	Stalls	Hoops	SED
Number of piglets			
Total born	11.2	11.1	0.384
Born alive	10.1	10.2	0.339
Still born	0.7	0.6	0.172
Mummified	0.3	0.3	0.074
Weaned	8.3 ^b	9.0 ^a	0.194
Birth to weaning piglet mortality ^a	1.9	1.2	
Born alive per sow mated	8.3 ^a	6.4 ^b	0.363
Weaned per sow mated	6.0	5.6	0.454
Litter weights			
Total litter weight at birth (kg)	16.3	16.1	0.499
Average weight at birth (kg)	1.6	1.6	0.022
Litter weight at weaning (kg)	72.0	71.3	2.09
Average weight at weaning (kg)	8.7	8.0	0.161

Within rows, significant differences are indicated by different superscripts; ^{a,b} $P < 0.05$.

^a Calculated as the difference between born alive and weaned.

lactation. The shorter lactation was due to a longer gestation in the Hoops sows and the fact that all piglets in each replicate for both treatments were weaned on the same day. Sows in the Stall treatment had more ($P < 0.01$) piglets per mated sow at farrowing but the difference was not significant at weaning.

3.6. Culls

The culling rate due to lameness was lower in the Hoops than in Stall treatment (0.7% versus 4.1%; $\chi^2_1 = 8.963$, $P < 0.01$). There was no treatment effect on culling for other reasons such as body condition. In replicate six, 11 experimental and 2 non-experimental sows died when they were mixed on an extremely hot day (45.7 °C), with anecdotal evidence of increased fighting and dehydration. Nevertheless, there was no treatment effect on sow mortality (2.8% and 1.7% for sows in the Stall and Hoops treatments, respectively).

4. Discussion

The approach to assess welfare risks in this experiment utilised an integrated approach measuring behavioural, physiological, health and fitness responses to assess biological functioning on the basis that difficult or inadequate adaptation generates welfare problems for animals (Broom and Johnson, 1993; Hemsworth, 2003).

Aggression was lower at week 9 than week 1 in the Hoops treatment in the present study, perhaps because the social hierarchy was established within the group. The number of scratches was significantly higher throughout gestation in the Hoops treatment, although it declined substantially over the successive assessments. Most of the scratches were probably a consequence of the initial aggression after mixing. However, the competition amongst sows in exiting the shed to reach the feeding station may have contributed later in gestation to maintain these minor injuries in these sows. While the differences were not statistically significant ($P = 0.06$), sows in the Hoops treatment had higher salivary cortisol concentrations in week 1 of

gestation. Increased salivary cortisol concentration in recently mixed pigs has been described by several authors (Sargent, 2001; Pajor, 2002). It is possible that cortisol concentrations had peaked within 24 h after the sows were mixed in the Hoops treatment and by day 5, when the samples were taken, the cortisol concentrations were already declining. Furthermore, aggression and injuries, particularly early in gestation and for older sows, might have been less if the study animals had had more experience with this housing system. For example, the older sows had experienced this system for only one previous gestation: in other gestations they were housed in stalls.

As with aggression and cortisol concentrations, there was a corresponding reduction in scratches in the Hoops treatment between weeks 1 and 9 of gestation and a further reduction by the end of the gestation. The higher reproductive failure in these sows may have resulted from the apparently higher stress response early in treatment, presumably associated with aggression following mixing. Research has shown that stress is associated with delayed ova transport (Razdan et al., 2001; Mwanza et al., 2000), higher levels of prostaglandin $F_{2\alpha}$ and lower embryo development (Razdan et al., 2002), leading to reproductive failure in sows.

The deteriorating locomotion score and the increasing culling associated with feet and leg problems in the Stall treatment have clear welfare implications for the sows in this treatment. Furthermore, sows in the Stall treatment spent more time lying in week 9 than sows in the Hoops treatment, possibly as a result of increasing feet and legs injuries. In a study of posture changes and leg strength (Marchant and Broom, 1994), there was evidence that sows in stalls had more difficulties in changing position. In the present study, sows in the Stalls treatment had a higher incidence of lameness and a higher incidence of abrasions. The physical restriction imposed by the gestation stall may have affected the lying posture of the sow and together with the solid floor, may have affected the sow's susceptibility to such injuries as well as exacerbating these injuries when they occurred. Bedding is a major factor reducing the incidence of lameness in dairy cows (Welcome, 2004). Therefore, the increasing liveweight, the restriction of movement and possibly the lack of bedding may have been responsible for the increasing feet and legs injuries in sows over time in the Stall treatment. The difference between treatments in the incidence of clinical lameness was greatest at week 15 of gestation. Coincidentally, most of the sows culled for lameness during gestation (i.e. those lame sows that were unable to stand due to the severity of the lameness) were culled in the last third of gestation. The reduced feet and leg injuries in the Hoops treatment may have also been due to the opportunity for these sows to be more easily detected as they walked daily to and from the feeding station, which would allow personnel to identify and treat early stage lameness.

Stressors can be deleterious to immune function leading to increased susceptibility of infectious disease and reduced stimulation from vaccination (Glaser and Kiecolt-Glaser, 2005). Several studies across a number of species have shown that increasing corticosteroids (endogenous or exogenous) concentrations result in a redistribution of white blood cells involved in the defence and immunological response against antigens, such as an increase of neutrophils (heterophils in poultry), a decrease of lymphocytes and thus a higher neutrophil:lymphocyte ratio (Gross and Siegel, 1983; Brown-Borg et al., 1993; Dhabhar et al., 1995, 1996; Dee, 1999). A higher percentage of neutrophils and a lower number and percentage of lymphocytes were found in the Stall sows in late gestation, suggesting immune dysfunction perhaps as a consequence of increased stress. Furthermore, sows in the Hoops treatment showed better immunological status on the basis of lymphocyte proliferation than sows in the Stall treatment. Although this latter treatment difference was not statistically significant, a 10% difference in lymphocyte proliferation might have implications for the animal's ability to resist disease challenges and

clearly needs to be investigated further. As all the blood cell sub-population counts in both treatments were within physiological levels for pigs (see Schalm et al., 1975), the possibility of disease contributing to these treatment effects is unlikely. Within the physiological range, the number of neutrophils was close to the upper limit and the number and percentage of lymphocytes were close to the lower limit in the Stall treatment suggesting that, at this point in gestation, these sows may have been under greater stress than sows in the Hoop treatment.

The results of the observation on the fear response to humans suggest that sows from the Stall treatment were more fearful of humans than sows from the Hoops treatment. Sows from the Stall treatment displayed a greater withdrawal response as the experimenter approached, delayed their return to the feed and consequently, spent less time near the feed. Studies by Hemsworth and co-workers (see Hemsworth and Coleman, 1998) indicate that pigs that show high levels of fear to humans may be chronically stressed when in regular contact with humans. The confirmation of higher fear responses, their causation and the contribution of increased fear to the welfare and health of stall-housed sows also require further study.

Both during treatment and also at the start of treatment, stalled sows had poorer body condition and higher number of abrasions. It was apparent that the stalled sows with poorer body condition were the ones showing multiple abrasions. Sows housed in stalls have higher maintenance requirements than sows housed in groups (National Research Council, 1998). Individually housed sows have a higher Lower Critical Temperature (LCT) than sows kept in groups and are required to metabolise a higher proportion of their energy intake to maintain body temperature (King, 1991). The poorer body condition of sows in the Stall treatment in the present study may be a consequence of their higher LCT. In addition, sows in stalls exhibited more stereotypical behaviour such as object manipulation (e.g. bar biting, floor licking and nosing) and champing, thereby possibly increasing their energy requirements (Cronin, 1986). Older sows in the Stall treatment had spent one or more winters in stalls and may have spent more energy than the sows in the Hoops treatment maintaining their body temperature, thus resulting in a deterioration in body condition. In contrast, sows in the Hoops treatment may have had the opportunity of recovering their body condition as the bedding may have helped in maintaining body temperature and providing some extra energy from bedding intake. Furthermore, the bedding occupied some of their time in lieu of stereotypical behaviour, which was not recorded in these sows.

While farrowing rate was 10% lower in the Hoops treatment, there were no treatment effects on litter size or litter weight at birth. Sows in the Stall treatment weaned heavier piglets, although this factor can be partly explained by the fact that the piglets from sows in the Hoops treatment had on average 2 days less of lactation. All sows were weaned on the same day however sows from the Hoops treatment farrowed on average 2 days later than the sows in the Stall treatment. On the other hand sows from the Hoops treatment weaned larger litters. The better physical condition based on locomotion score, in the Hoops treatment in lactation may have improved piglet survival through for example more controlled posture changes in the farrowing crate reducing the risks of piglet crushing. However, based on farrowing rates and litter size, sows in the Stall treatment had 39 more piglets weaned per 100 mated sows.

Consideration of the welfare implications of group versus stall housing during gestation is complex in that both housing systems have some clear advantages and disadvantages in relation to pig welfare. It is also difficult to clearly identify all the contributing factors because of differences that are part of the housing system per se and the constraints that affect the conduct of this type of research. For example, the two treatments were located in separate buildings because there was no adequate infrastructure to house such large number of sows in the same location.

This situation led to different stockpeople caring for the animals during gestation. Thus, some caution is required in interpreting the results. Nevertheless, it is concluded that while challenges to adapt to treatment early in gestation may have been greater in sows in the Hoops than in Stalls, there is some evidence that the sows in the Stall treatment may have had greater challenges adapting late in gestation. Aggression and stress in grouped gestating sows raise concerns for sows in the Hoops treatment early in gestation. Stalls, when designed properly, are very effective in the reduction of aggression that occurs immediately after mixing unfamiliar sows in groups. However, the increasing feet and leg problems, increased fear of humans and the changes in leucocytes populations, perhaps as a consequence of increased stress, in the Stall treatment sows, raise welfare concerns for these sows late in gestation and perhaps for the newborn piglets. In addition, the evidence of stereotypical behaviour may indicate some disadvantages for sows kept in stalls for the whole gestation. The measurements taken in this study were limited however they raise a number of welfare issues for both housing systems and clearly more detailed research is required.

Acknowledgements

The Department of Primary Industries' Animal Ethics Committee (AEC) granted ethics approval for this experiment. This research was funded by the Australian Pork Limited (Project Number 1825) and the Department of Primary Industries, Victoria, Australia. The technical advice of Drs. John Barnett and Greg Cronin and the statistical advice of Mr. Kym Butler are gratefully acknowledged.

References

- Barnett, J.L., Hemsworth, P.H., Cronin, G.M., Jongman, E.C., Hutson, G.D., 2001. A review of the welfare issues for sows and piglets in relation to housing. *Aust. J. Agric. Res.* 52, 1–28.
- Barnett, J.L., Hemsworth, P.H., 2003. Science and its application in assessing the welfare of laying hens in the egg industry. *Vet. J.* 81, 615–623.
- Broom, D.M., Johnson, K.G., 1993. *Stress and Animal Welfare*. Chapman and Hall, London, UK.
- Brown-Borg, H.M., Klemcke, H.G., Blecha, F., 1993. Lymphocyte proliferative responses in neonatal pigs with high or low plasma cortisol concentration after stress induced by restraint. *Am. J. Vet. Res.* 54, 2015–2020.
- de Koning, R., 1993. Sow welfare: ekesbo assessment and planning. *Pig J.* 30, 30–40.
- Dee, S., 1999. Weaned pig immunology and stress. In: *Compendium on Continuing Education for the Practicing Veterinarian*, vol. 21, pp. S144–S147.
- Dhabhar, F.S., Miller, A.H., McEwen, B.S., Spencer, R.L., 1995. Effects of stress on immune cell distribution: dynamics and hormonal mechanisms. *J. Immun.* 154, 5511–5527.
- Dhabhar, F.S., Miller, A.H., McEwen, B.S., Spencer, R.L., 1996. Stress-induced changes in blood leukocyte distribution: role of adrenal steroid hormones. *J. Immun.* 15, 1638–1644.
- Glaser, R., Kiecolt-Glaser, J.K., 2005. Stress-induced immune dysfunction: implications for health. *Nat. Rev.* 5, 243–250.
- Gross, W.B., Siegel, H.S., 1983. Evaluation of the heterophil/lymphocyte ratio as a measure of stress in chickens. *Avian Dis.* 27, 972–979.
- Hemsworth, P.H., Coleman, G.J., 1998. *Human-livestock interactions: The stockperson and the productivity and welfare of intensively farmed animals*. CABI, London, UK.
- Hemsworth, P.H., Brand, A., Willems, P., 1981. The behavioural response of sows to the presence of human beings and its relation to productivity. *Livestock Prod. Sci.* 8, 67–74.
- Hemsworth, P.H., Barnett, J.L., Coleman, G.J., Hansen, C., 1989. A study of the relationships between the attitudinal and behavioural profiles of stockpersons and the level of fear of humans and reproductive performance of commercial pigs. *Appl. Anim. Behav. Sci.* 23, 301–314.
- Hemsworth, P.H., Pedersen, V., Cox, M., Cronin, G.M., Coleman, G.J., 1999. A note on the relationship between the behavioural response of lactating sows to humans and the survival of their piglets. *Appl. Anim. Behav. Sci.* 65, 43–52.

- Hemsworth, P.H., 2003. Studying difficult and inadequate adaptation to assess animal welfare. In: Paterson, J.E. (Ed.), Australasian Pig Science Association, Werribee, Victoria, Australia, Proceedings of the Ninth Biennial Conference of the Australian Pig Science Association held in Fremantle, Western Australia, Australia, pp. 100–106.
- King, R., 1991. The basics of sow feeding and management. In: Proceedings Saskatchewan Pork Industry Symposium, Saskatoon, Saskatchewan, Canada, pp. 47–51.
- Marchant, J.N., Broom, D.M., 1994. Effects of housing system on movement and leg strength in sows. *Appl. Anim. Behav. Sci.* 41 (3–4), 275–276.
- Mwanza, A.M., Madej, A., Kindahl, H., Lundeheim, N., Einarsson, S., 2000. Postovulatory effect of repeated intravenous administration of ACTH on the contractile activity of the oviduct, ova transport and endocrine status of recently ovulated and unrestrained sows. *Theriogen* 54, 1305–1316.
- National Research Council, 1998. Nutrient requirements for swine, 10th edition. National Academy Press, Washington, USA.
- Pajor, E.A., 2002. Group housing of sows in small pens: advantages, disadvantages and recent research. In: Reynnells, R. (Ed.), Proceedings: Symposium on Swine Housing and Well-being. U.S. Departments of Agriculture, Agricultural Research Service, National Agricultural Library, Animal Welfare Information Centre, pp. 37–44.
- Razdan, P., Mwanza, A.M., Kindahl, H., Hulten, F., Einarsson, S., 2001. Impact of post ovulatory food deprivation on the ova transport, hormonal profiles and metabolic changes in sows. *Acta Agric. Scand.* 45–55.
- Razdan, P., Mwanza, A.M., Kindahl, H., Rodriguez-Martinez, H., Hulten, F., Einarsson, S., 2002. Effect of repeated ACTH-stimulation on early embryonic development and hormonal profiles in sows. *Anim. Reprod. Sci.* 70, 127–137.
- Sargent, R.S., 2001. The social and feeding behaviour of growing pigs in deep-litter, large group housing systems. Ph.D. Thesis. The University of Melbourne.
- Schalm, O.W., Jain, N.C., Carroll, E.J., 1975. *Veterinary Haematology*, 3rd edn. Lea & Febiger, Philadelphia, USA.
- Snider III, T.G., Williams, J.C., Karns, P.A., Romaine, T.L., Trammel, H.E., Kearney, M.T., 1986. Immunosuppression of lymphocyte blastogenesis in cattle infected with *Ostertagia ostertagi* and/or *Thichostrongilus axei*. *Vet. Immunol. Immunopathol.* 11, 151–264.
- Welcome, F., 2004. Cow comfort and health through bedding management. Northeast Dairy Business, <http://www.dairybusiness.com/northeast/April03/F3%20p26,27,28%20edding%20manage.pdf>.