Published November 25, 2014

Effects of group size and floor space allowance on grouped sows: Aggression, stress, skin injuries, and reproductive performance[1]

P. H. Hemsworth,*[2] M. Rice,* J. Nash,* K. Giri,† K. L. Butler,† A. J. Tilbrook,‡[3] and R. S. Morrison§

*Animal Welfare Science Centre, Melbourne School of Land and Environment, University of Melbourne, Parkville, VIC 3010, Australia; †Animal Welfare Science Centre, Department of Primary Industries, 600 Sneydes Road, Werribee, VIC 3030, Australia; ‡Animal Welfare Science Centre, Department of Physiology, Monash University, Clayton, VIC 3800 Australia; and §Rivalea Australia, Corowa, NSW 2646, Australia.

ABSTRACT: A total of 3,120 sows, in 4 time replicates, were used to determine the effects of group size and floor space on sow welfare using behavioral, physiological, health, and fitness variables. Within 1 to 7 d postinsemination, sows were assigned randomly to treatments of a 3 by 6 factorial arrangement, with 3 group sizes (10, 30, or 80 sows/pen) and 6 floor space allowances (1.4, 1.8, 2.0, 2.2, 2.4, or 3.0 m^2/sow). Sows were housed on partially slatted concrete floors, and overhead feeders delivered 4 times/day to provide a total of 2.5 kg of feed/sow. As pen space increased from 1.4 to 3.0 m^2/sow, aggression at feeding decreased from about 9 to 7 bouts/sow (linear, $P = 0.029$) and plasma cortisol concentrations decreased from about 28 to 21 ng/mL (linear, $P = 0.0089$) at 2 d. Although the results are in accord with a linear decline from 1.4 to 3 m^2/sow, the results are also in accord with a decline in these measurements from 1.4 to 1.8 m^2/sow and no further decline greater than 1.8 m^2/sow. Farrowing rate (percentage of inseminated sows that farrowed) also increased from about 60 to 75% as space increased from 1.4 to 3.0 m^2/sow (linear, $P = 0.012$). Group size was related to skin injuries on d 9 ($P = 0.0017$), 23 ($P = 0.0046$), and 51 ($P = 0.0006$), with groups of 10 consistently having the lowest number of total injuries over this period. Based on the aggression and cortisol results, it is credible to judge that, within the range of floor space allowances studied, sow welfare improves with increased space. However, from a sow welfare perspective, the experiment had insufficient precision to determine what is an adequate space allowance for sows. Thus, although the results definitely support a space allowance of 1.4 m^2/sow being too small, it is not possible to give guidance on an actual space allowance at mixing that is adequate.

Key words: group, group size, reproduction, sows, space, welfare

© 2013 American Society of Animal Science. All rights reserved. J. Anim. Sci. 2013.91:4953–4964
doi:10.2527/jas2012-5807

INTRODUCTION

There appears to be increasing concern with society's treatment of animals (Fraser, 2008). Confinement housing of livestock, in particular housing of gestating sows, appears to be at the forefront of these concerns, which in turn has led to legislative, consumer, and retailer pressure to increase the use of group housing of gestating sows.

International industry experience, however, indicates that the opportunity for group housing to improve sow welfare is presently limited by high levels of aggression that are commonly observed in newly formed groups of sows after mixing (Verlarde, 2007). This aggression, especially if intense and prolonged, may lead to injuries and stress. Nevertheless, there are few rigorous recommendations in the scientific literature on the design features of sow group housing that reduce aggression (Arey and Edwards, 1998; Barnett et al., 2001). Although the problem of pig aggression has received considerable attention, detailed studies of aggressive behavior have generally used staged paired

[1]The research reported here was supported by the Australian Pork Limited, Barton, ACT 2600, Australia. The authors gratefully acknowledge M. Karlen, D. Broek, M. Tull, and K. Tickle for technical assistance.
[2]Corresponding author: phh@unimelb.edu.au
[3]Current address: South Australian Research & Development Institute, University of Adelaide, Roseworthy, SA 5371, Australia.
Received September 3, 2012.
Accepted July 3, 2013.

encounters or small group sizes, which are very different from commercial settings.

Both floor space and group size may affect aggression and stress in group-housed sows. There is limited evidence that reducing floor space may increase aggression, injuries, and plasma cortisol concentrations in group-housed gilts and sows (Barnett et al., 1992; Weng et al., 1998; Salak-Johnson et al., 2007). Olsson et al. (1994) reported increased injuries as group size increased, whereas Taylor et al. (1997) found that varying group sizes of 5, 10, 20, and 40 sows with a space allowance of 2.0 m^2/sow had no effects on skin injuries. Therefore, the objective of this experiment was to determine the effects of floor space allowance and group size on aggression, stress, skin injuries, and reproductive performance in sows housed in groups after insemination.

MATERIALS AND METHODS

Animals, Housing, and Experimental Design

This experiment was conducted between September 2008 and January 2010 in a gestation unit of a large commercial piggery in southern New South Wales, Australia, specifically renovated for this experiment. This 61- by 19-m building was equipped with adjustable blinds and overhead water sprinklers, covering the 50% slatted floor area of the pens, that were activated (3 min on and 15 min off) when the internal temperature exceeded 26°C.

All animal procedures were conducted with prior institutional ethical approval under the requirements of the NSW Prevention of Cruelty to Animals Act 1985, in accordance with the National Health and Medical Research Council/Commonwealth Scientific and Industrial Research Organization/Australian Animal Commission *Code of Practice for the Care and Use of Animals for Scientific Purposes.*

A total of 3,120 sows, in 4 time replicates (780 sows/replicate) over 13 mo were studied. Landrace × Large White sows of mixed parity (2 and older) were of good health at the beginning of the experiment, and were introduced to the postinsemination housing treatments within 1 to 7 d of insemination. Within each time replicate, sows were assigned to postinsemination treatments of a 3 by 6 factorial arrangement, with 3 group sizes (10, 30, or 80 sows/pen) and 6 floor space allowances (1.4, 1.8, 2.0, 2.2, 2.4, or 3.0 m^2/sow).

In each time replicate, there was one treatment (pen) of each group size and space allowance combination. Furthermore, an extra pen of 10 sows for each space allowance was included in each time replicate to sample sufficient sows for the physiological and injury variables in each treatment, and to obtain similar residual variance for all treatments (that is, to allow 20 sows to be sampled in each treatment, within each replicate); thus, there were 24 pens in total within the facility, one pen of each space allowance for the group sizes of 30 and 80, and 2 pens of each space allowance for the group size of 10.

The 24 experimental pens were located within the same area of the experimental building (Fig. 1). The 3 group sizes were located down the length of the building, but because of construction limitations, the groups of 80 were located in the 2 outside rows of pens and the groups of 10 and 30 were located in the 2 inner rows of pens. The length of the building was divided into 3 subreplicate blocks so that, within a subreplicate block, the outer and inner rows each contained an 80 group size treatment and each of the 2 inner rows contained both a 10 group size (2 pens) and a 30 group size treatment. The inner and outer row pens were 3.82 and 6.10 m deep, respectively, and the width of the pens were varied to provide the space allowances of 1.4, 1.8, 2.0, 2.2, 2.4, and 3.0 m^2/sow. At each space allowance, the two 10 group size pens were adjacent. Each pen had concrete floors with 50% slatted at the rear of the pens. Drop feeders, evenly suspended across the width of each pen (1 drop feeder/5 sows), were used to deliver feed, which was delivered 4 times/d (0700, 0800, 0900, and 1000 h) to provide a total of 2.5 kg/sow of a commercial diet (13.1 MJ/kg DM, and 12.8% CP protein). Sows had ad libitum access to water via nipple drinkers (1 drinker/5 sows) evenly distributed along the back wall of each pen over the slatted flooring.

Each time replicate was introduced into the experiment over a 6-wk period. On alternate Mondays within each time replicate, sows (n = 260) were housed after weaning—during and after 2 inseminations—in stalls before being selected and allocated to treatment. Within 1 wk of insemination, sows were moved to their allocated housing treatment as a complete group. Sows remained in their treatment pens, unless culled for reproductive failure, injuries, or poor health, and at 105 d were relocated to a farrowing house for the remaining few days of gestation. Introduction to the allocated housing treatment was considered Day 1 of treatment. Sows were introduced to treatment pens in replicates 1, 2, 3, and 4 in late September 2008, early January 2009, late March 2009, and early August 2009, respectively.

Regular checks for return to estrus were conducted daily from 3 wk after insemination, as well as a pregnancy test using ultrasonography at 5 wk after insemination. Sows that returned to estrus, those that tested negative at the pregnancy test, and those with injury or in poor health were removed from treatment pens, and not replaced in the groups by other sows.

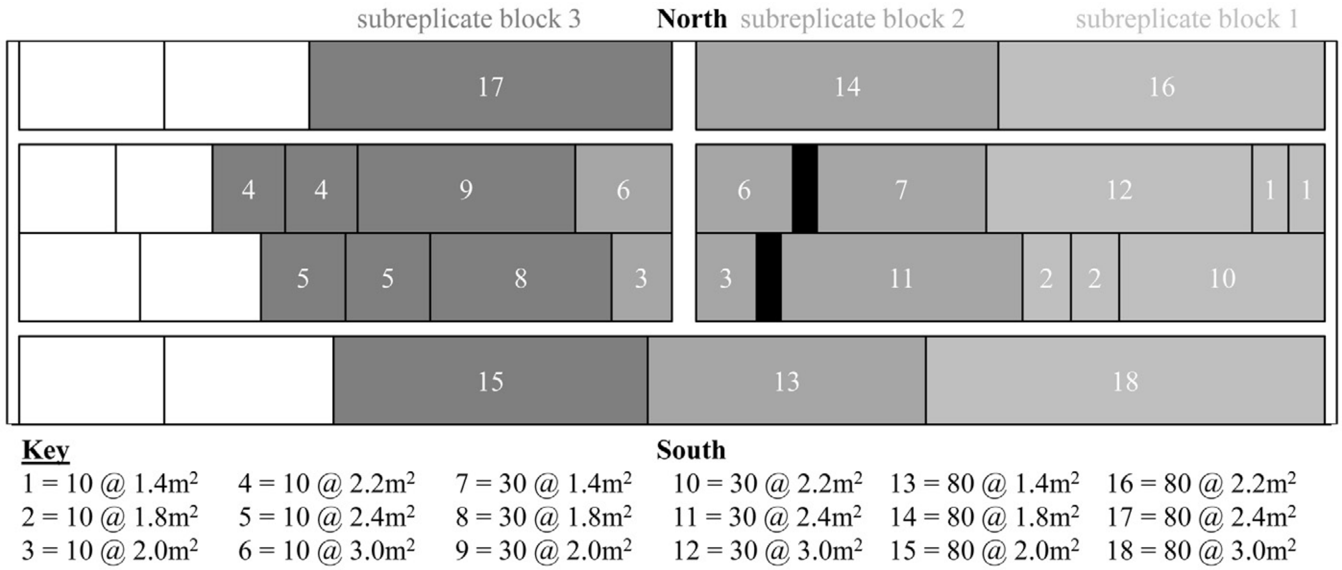

Figure 1. Layout of experimental pens in the accommodation building (image not to scale).

Measurements

Aggressive Behavior at Feeding. Aggression between group-housed sows that are restrictively fed is most pronounced when feeding or accessing feeding areas (Arey and Edwards, 1998; Barnett et al., 2001; Bench et al., 2013). To observe aggressive behavior at feeding, 3.6-mm infrared closed circuit television cameras were installed overhead near a feeder to record behavior at the time that feed was distributed on the solid floor below the drop feeder. The focal range of each camera matched the dimensions of the smallest pen size (10 sows with 1.4 m^2/sow), or 14 m^2, which allowed a constant floor area to be recorded at each feed drop. Apart from each pen of 10 sows in which one camera was installed overhead, all the other pens had 2 cameras installed. The cameras continuously recorded from 0600 to 1700 h for 3 d, commencing at d 2 and d 8 of treatment.

From the digital video recordings, continuous observations were conducted to measure the number of bouts of aggressive behavior in the 30 min following each feed drop on d 2 and 8. A bout criterion interval of 5 s was chosen to separate one bout of aggressive behavior from another bout of the same behavior by an individual sow. Aggressive behaviors recorded were slashes, butts, pushes, and bites, and these were distinguished from other tactile interactions with sows on the basis that the former were associated with avoidance or retaliation by 1 sow as a consequence of the interaction. Only aggressive interactions in which the head of the sow (defined as extending from the snout to the ears) displaying the aggressive behavior was clearly visible were recorded. The identity of each sow was not recorded because aggression at the level of the group was the main focus.

The average number of sows in the field of view was recorded at regular intervals so that the number of bouts of aggression could be expressed on the basis of the average number of sows in the field of view during the observations. Point or instantaneous scans at 30-s intervals during each 5-min block of footage were used to count the number of sows in each scan, providing an estimate of the average number of sows in the field of view during each 5-min block of the observation period. Thus, the frequency of bouts of aggression after each feed drop was calculated on a "per sow in field of view" basis. The frequency of aggression per sow during the 4 30-min periods following the feed drops on d 2 and 8 was collated and analyzed for each pen.

Skin Injuries. On each of d 2, 9, 23, and 51, 20 sows in each treatment were assessed for skin injuries by 2 technicians as described by Karlen et al. (2007). All sows in each pair of pens with 10 sows were assessed, whereas the first sow sighted from the central and peripheral areas of the pens containing 30 or 80 sows, were assessed by the observer. Skin injuries were categorized into fresh injuries (scratches, abrasions, cuts, and abscesses), or partially healed or old injuries. Each side of the sow's body was divided into 21 areas for injury data collection (see Karlen et al., 2007). The number and the type of skin injuries were recorded, and, from these records, the number of both fresh and total injuries (fresh and old injuries) were collated for each sow on each observation day. In addition, sows culled for nonreproductive reasons, such as injury or illness, were recorded for each pen.

Physiology. Blood samples were collected via jugular venipuncture (10-mL lithium-heparinized tubes; BD Vacutainer BD, Belliver Industrial Estate, Plymouth, UK) of sows restrained with a snout snare. Sampling commenced at 1300 h and 20 sows from each experimental unit by 3 technicians (all sows in each pair of pens with 10 sows, as well as the first sow sighted from the central and peripheral areas of pens containing 30 or 80 sows) on d 2, 9 or 10 and 51 or 52. On d 2, sows in pens of 30 and 80 were sampled in groups of 10, with 30 min between each sample period, whereas on d 9 and 51, sampling was conducted over 2 d with 10 sows in pens of 30 and 80 sampled on each day. Blood samples were collected within 2 min of snaring to avoid an acute stress response to handling influencing the basal concentrations of plasma cortisol (Broom and Johnson, 1993) and all batches of 10 sows took less than 10 min to collect. Karlen et al. (2007) reported that repeated sampling of different sows within three groups of 85 over 30 min did not affect salivary cortisol concentrations. Two 10-mL blood samples were collected from each sow for subsequent analyses of plasma cortisol and white blood cell count.

The blood samples for cortisol were centrifuged for 10 min at 1,912 × g at 4°C, with the plasma drawn off into individual micro tubes and frozen. Samples from each pen were pooled using 200-μL aliquots from each individual sample and assayed for total and free cortisol concentrations. Plasma cortisol was measured with an extracted RIA (Bocking et al., 1986), using hydrocortisone (H-4001; Sigma Chemical Co., St Louis, MO) as the standard. The assay utilized [^{3}H]-cortisol (Amersham Pharmacia Biotech, UK, Buckinghamshire HP, England) as tracer and a dichloromethane extraction procedure with a mean (±SEM) recovery of 93.2 ± 2.8%. The sensitivity for the 6 assays ranged from 0.15 to 0.47 ng/mL, with a mean of 0.33ng/mL and the intra- and interassay CV were 7.81 and the 12.06%, respectively.

Blood samples collected for haematology were transported on ice to an Australian commercial laboratory and the absolute numbers of neutrophil and lymphocyte cells were measured on individual sow samples in a CellDyn 3700 autoanalyzer (Abbott Diagnostic Division, Abbott Park, IL). The neutrophil-to-lymphocyte ratio was calculated for each pen at d 2, 9, and 51 of the experiment.

Sow Performance. All sows were weighed and P2 backfat measurements were taken just before entry to treatment and before entering the farrowing accommodation (d 110). All the sows farrowed in a common farrowing environment and data collected included farrowing rate and litter size (number of piglets born alive, stillborn, and mummified). Stillborn piglets were judged on the basis that they were fully formed at farrowing, covered in fetal membrane, had fully-formed eponychia on their hooves and were located behind the sow. Data on sows confirmed pregnant but failed to farrow, and abortions were also collected, as well as sows culled for injury.

Statistical Analyses

Each measurement was analyzed using a series of REML mixed model analyses that included treatment effect combinations, as well as the a priori of replicate as a fixed effect and random effects of row (replicate), subreplicate block (replicate) and row × subreplicate block (replicate). In all REML analyses, the experimental unit was all sows being measured in a pen (2 pens with 10 group size treatments) within a replicate. The BW change analyses also included a covariate fixed effect of preexperimental BW to improve precision, whereas several measurements were either square root, logarithmically transformed, or angularly transformed (Table 1) before REML analyses to reduce skewness of residuals. One pen, with an exceptionally large number of fresh injuries and total injuries at d 23, was excluded as a statistical outlier for these 2 measurements. Another pen with exceptionally good farrowing rates for its replicate and treatment was excluded as a statistical outlier for farrowing rate. The pooled free cortisol concentrations at d 2 were extremely large for 1 of the 2 samples from each of 2 pens of 30 sows; thus the measurement of free cortisol at d 2 for the pens was calculated from a single sample, rather than the average of 2 samples. For measurements that were calculated using all sows, a dot histogram of residuals from a saturated-treatment model was drawn for each group size, so that the possibility of different amounts of random variation with group size could be examined. In no case was there any large change in the amount of residual variation with group size.

At each measurement occasion, REML models were fitted with different treatment effects, including: 1) no treatment effects; 2) additive effects of group size and a linear response to the amount of space/sow; 3) additive effects of group size and a quadratic response to the amount of space/sow; and 4) a saturated treatment model of all combinations of group size and space/sow. From these models, Wald F-tests were calculated for 1) group size after adjusting for an additive quadratic response to space per sow; 2) a linear response to space for sow adjusted for an additive effect of group size; 3) a quadratic response to space for sow adjusted for an additive effect of group size; and 4) any effect of group size and space/sow combinations in addition to additive effects of group size and the quadratic response to space per sow (that is, a single test of a combined term for the deviations from a quadratic response for the main effect of space allowance and any interaction of space allowance with group size). These tests allowed a parsimonious treatment model to be selected for each measurement. Wald chi-square tests were occasionally substituted for the Wald F-tests, when the Wald F-tests could not be numerically calculated (Table 1).

Table 1. Probability values of tests for choosing the treatment effects of parsimonious models for each measurement ($P < 0.05$ in bold)

	GS[1]	SpaceVar[1]	SpaceVarSq[1]	Any further treatment effect	
	Terms adjusted for				
Measurement	SpaceVar + SpaceVarSq	GS	GS + SpaceVar	Effects in previous 3 columns	Treatment effects selected
Aggressive behavior at feeding					
Aggression, d 2[2]	0.48	**0.029**	0.34	0.29	SpaceVar
Aggression, d 8[2]	0.50	0.72	0.29	0.61	none
Physiology					
Total cortisol, d 2	0.48	**0.0089**	0.052	**0.13**	SpaceVar
Total cortisol, d 9	0.35	0.23	0.47	0.013	none
Total cortisol, d 51	0.27	0.12	0.19	0.90	none
Free cortisol, d 2[3]	0.41	**0.036**	0.080	0.13	SpaceVar
Free cortisol, d 9[3]	0.45	0.085	0.57	**0.0010**	none
Free cortisol, d 51[3]	0.94	0.76	0.14	0.78	none
Neutrophil-lymphocyte ratio, d 2[3]	**0.0092**	0.99	0.85	0.48	GS
Neutrophil-lymphocyte ratio, d 9[3]	0.18	0.94	**0.0080**	0.80	SpaceVar + SpaceVarSq
Neutrophil- lymphocyte ratio, d 51[3]	**0.027**	0.063	0.28	0.76	GS
Injuries					
Fresh injuries, d 2[2]	0.57	0.59	0.19	0.70	none[6]
Fresh injuries, d 9[2]	**0.045**	0.099	0.91	0.12	GS
Fresh injuries, d 23[2]	0.40	0.37	0.99	0.14	none
Fresh injuries, d 51[2]	0.56	0.62	**0.031**	0.69	none
Total injuries, d 2[2]	0.50	0.39	0.32	0.41	none
Total injuries, d 9[2]	**0.0017**	0.36	0.44	0.17	GS
Total injuries, d 23[2]	**0.0046**	0.67	0.81	**<0.0001**	GS
Total injuries, d 51[2]	**0.0006**[6]	0.17	**0.020**	0.94[5]	GS
Culled for nonreproductive reasons[4]	0.052	0.10	0.86	0.42	none
Reproductive performance					
Born alive	0.66	0.13	0.71	0.15	none
Still born	0.56	0.94	0.22	0.97	none
Mummies	0.34	0.47	0.46	0.15	none
Farrowing rate	0.77	**0.012**	0.37	0.74	SpaceVar
BW and backfat					
Change in backfat P2	0.12	**0.028**	**0.012**	0.56	SpaceVar + SpaceVarSq
Change in live weight	**0.013**	0.80	0.15	0.63	GS

[1]GS, group size; SpaceVar = linear response to sow space; SpaceVarSq = quadratic response to sow space.

[2]Square-root-transformed data.

[3]Logarithmically-transformed data.

[4]Angularly-transformed data.

[5]Random effect for row was fixed at 0 to achieve numerical convergence.

[6]Wald chi-square test was used because the calculation of *F*-test failed numerically.

Predicted values from the parsimonious models were graphed, with the values back-transformed when necessary, as a function of space/sow. In these graphs, the predicted means of each group size × space allowance combination are presented as individual points (after back transformation when necessary), using the saturated model of treatment effects.

RESULTS

A total of 30 sows (0.96% of sows) were removed from the experiment before d 9 of treatment due to injury or escaping from their pens.

Aggressive Behavior at Feeding

Aggression at d 2 declined (linear, $P = 0.029$) from about 9 bouts/sow to about 7 bouts/sow as space in-

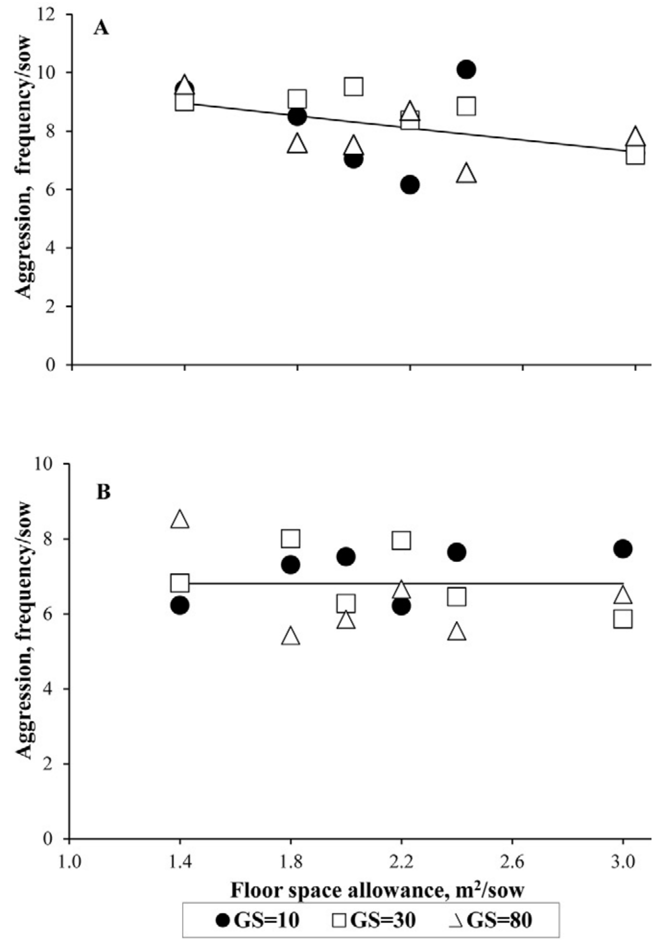

Figure 2. Predicted values of aggression as affected by floor space allowance on: A) d 2 and B) d 8. GS = group size.

creased from 1.4 m^2/sow to 3.0 m^2/sow (Table 1, Fig. 2); however, there was no relationship ($P \geq 0.29$) found between space and aggression at feeding on d 8. No relationship ($P \geq 0.48$) was found between group size and aggression at feeding at either day (Table 1).

Physiology

At d 2, total cortisol concentrations declined (linear, $P = 0.0089$) from about 30 to about 20 ng/mL as space increased from 1.4 to 3.0 m^2/sow (Fig. 3), whereas free cortisol declined (linear, $P = 0.036$) from about 4.5 to about 3 ng/mL over the same space range (Fig. 4). In contrast, at d 2, no relationship was found between group size and total ($P = 0.48$) and free ($P = 0.41$) cortisol concentrations (Table 1).

There was statistical evidence of group size and space responses that could not be explained by a combination of additive effects of group size and a quadratic to space for both total ($P = 0.013$) and free ($P = 0.001$) cortisol at d 9, respectively (Table 1); however, these effects were associated with biologically unusual responses to space at a group size of 10 (Fig. 3 and 4); thus, the

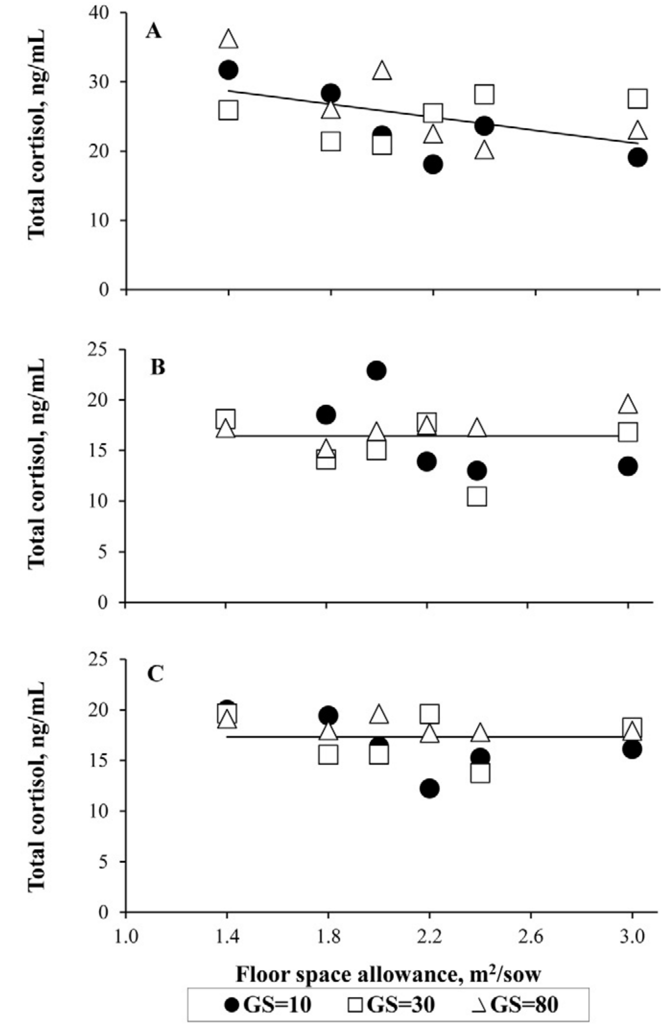

Figure 3. Predicted values of total cortisol concentrations as affected by floor space allowance on: A) d 2, B) d 9, and C) d 51. GS = group size.

effects were most likely associated with chance. Apart from these possible effects, there was no indication of group size and space effects on total or free cortisol at d 9 ($P \geq 0.085$) and 51 ($P \geq 0.12$).

There was evidence that the neutrophil-to-lymphocyte ratios in groups of 10 were less ($P = 0.0092$) than in groups of 30 and 80 at d 2, and that the neutrophil-to-lymphocyte ratios in groups of 10 and 30 were less ($P = 0.027$) than in groups of 80 at d 51 (Fig. 5). However, no group size effect was observed at d 9 ($P = 0.18$). There was also some evidence of a quadratic ($P = 0.008$) response to space at d 9, whereby a higher neutrophil-to-lymphocyte ratio was associated with 1.4 m^2 and 3.0 m^2/sow of floor space (Table 1); however, no space responses were detected at d 2 ($P \geq 0.85$) and 51 ($P \geq 0.063$).

Skin Injuries

Total injuries were greatest in groups of 30 at d 9 ($P = 0.0017$) and 23 ($P = 0.0046$) and highest in groups of 80 at d 51 ($P = 0.0006$), but groups of 10 had consistently

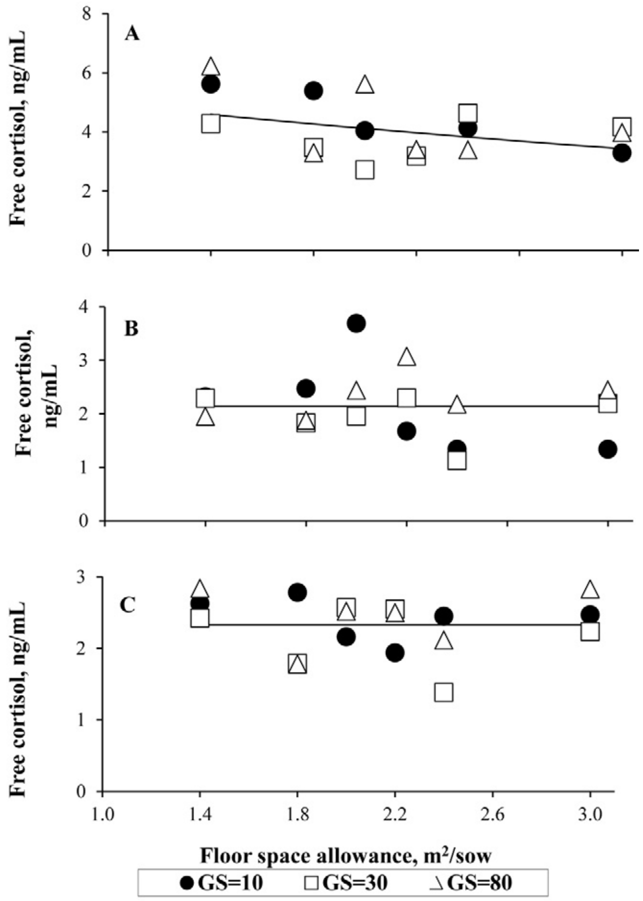

Figure 4. Predicted values of free cortisol concentrations as affected by floor space allowance on: A) d 2, B) d 9, and C) d 51. GS = group size.

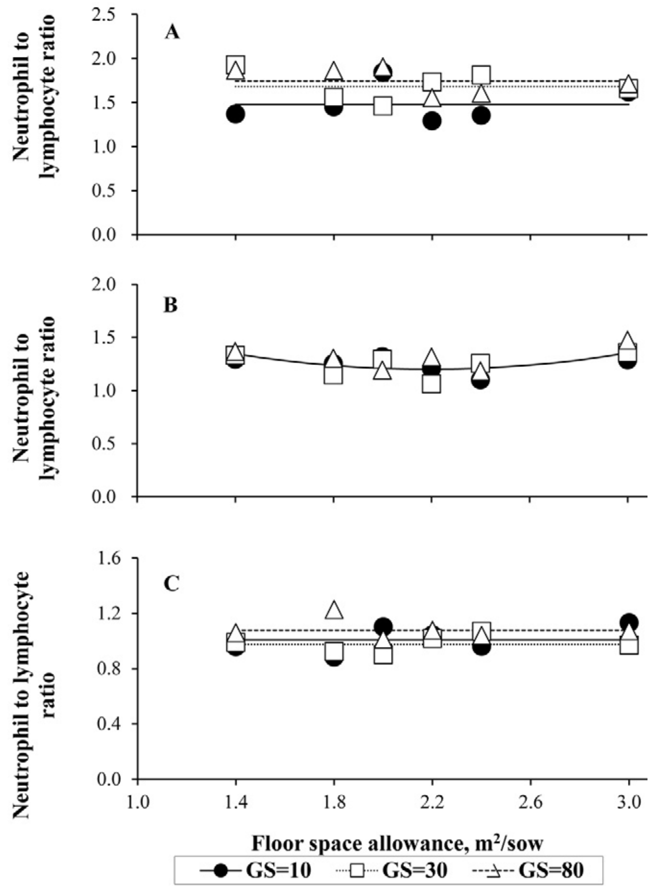

Figure 5. Predicted values of neutrophil to lymphocyte ratios as affected by floor space allowance on: A) d 2, B) d 9, and C) d 51. GS = group size.

low injuries from d 9 to 51 (Fig. 6). There was no (P = 0.50) relationship found between group size and total injuries at d 2 (Table 1). Moreover, there was a greater (P = 0.045) incidence of fresh injuries with a group size of 80 at d 9 (Fig. 7); otherwise, there was no ($P \geq 0.40$) relationship between group size and the prevalence of fresh injuries at d 2, 23, and 51 (Table 1).

There was statistical evidence of effects of group size and space allowance ($P < 0.0001$) for total injuries on d 23 that cannot be described by additive effects of group size and quadratic response to space allowance (Table 1), but the form of response was difficult to explain biologically. These effects could very well be due to chance. There was some evidence of a quadratic response to space for fresh (P = 0.031) and total injuries (P = 0.02) at d 51, but there was no ($P \geq 0.17$) corresponding linear response (Table 1).

Sow Performance

There were no relationships between group size or space on the proportion of sows culled for nonreproductive reasons ($P \geq 0.052$; Fig. 8), litter size ($P \geq 0.13$; Fig. 9), numbers of stillborn ($P \geq 0.22$; Fig. 10), and mummified pigs ($P \geq 0.34$; Fig. 11). However, farrowing rate increased (linear, P = 0.012) from about 60 to 75% as floor space increased from 1.4 to 3.0 m^2/sow (Fig. 12). These values were low because the average farrowing rate was only 43% in replicate 2 which occurred during midsummer. Finally, BW gain was almost 10 kg greater (P = 0.013) in groups of 10 than in groups of 30 or 80 (Fig. 13), whereas backfat gain was greatest (quadratic, P = 0.012) in a floor space of 1.4 m^2/sow (Fig. 14).

DISCUSSION

There were few interactions between group size and space allowance observed in this experiment; in fact, there was no measurement in which the parsimonious model included both group size and space allowance. The important implication from this is that it is legitimate to discuss space allowance effects without the need to refer to group size effects, and it is legitimate to discuss group size effects without the need to refer to space allowance effects.

One of the most consistent effects was the effect of floor space allowance on several parameters early in the treatment period. A key finding was that increased space led to reduced aggression at feeding and lower total and

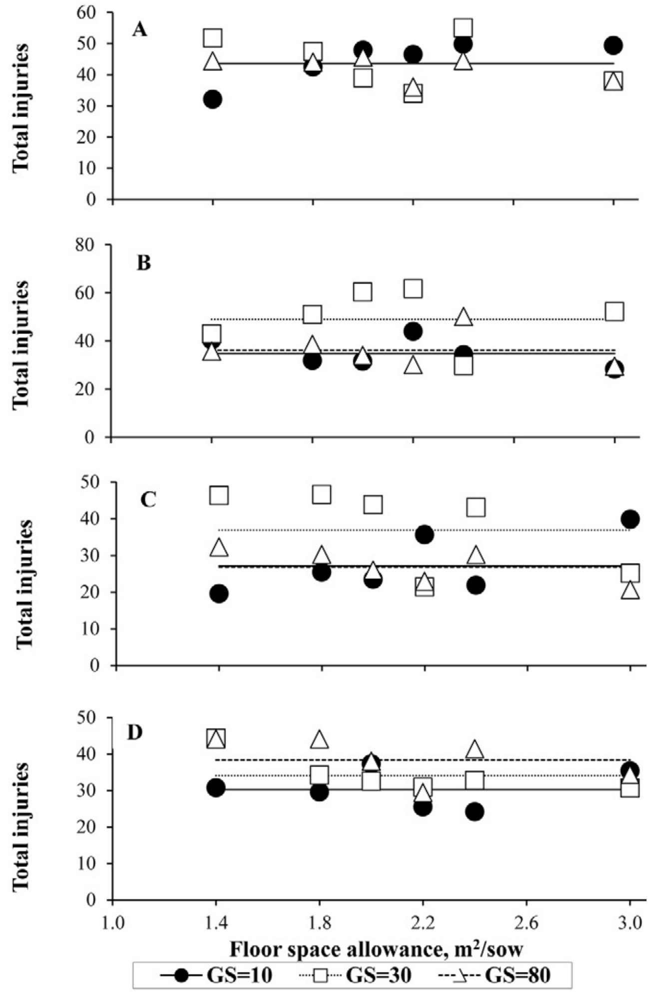

Figure 6. Predicted values of total injuries/sow as affected by floor space allowance on: A) d 2, B) d 9, C) d 23, and D) d 51. GS = group size.

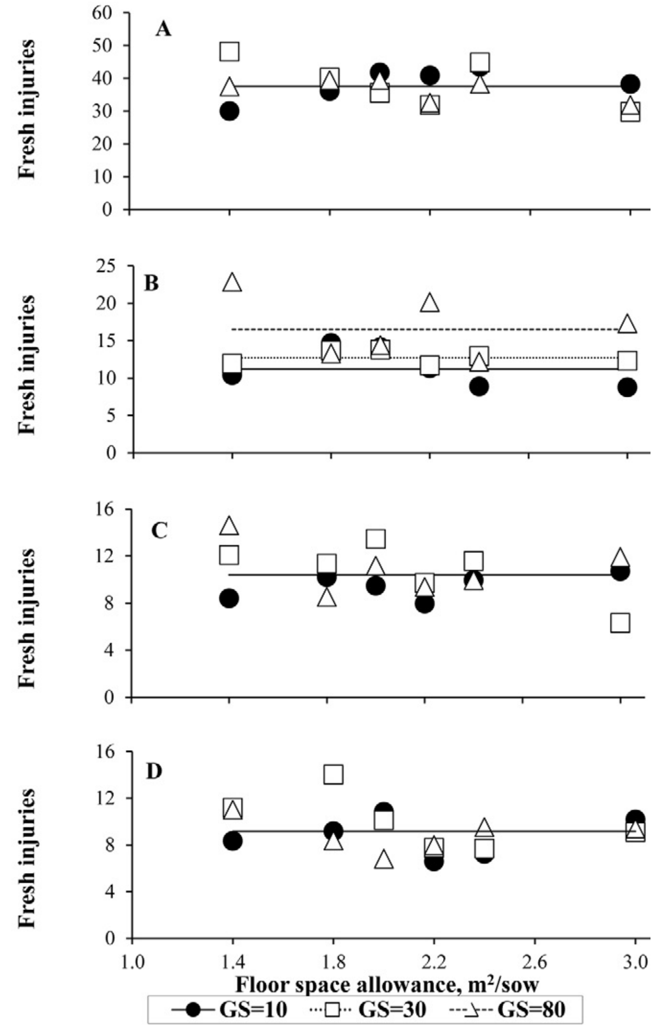

Figure 7. Predicted values of fresh injuries/sow as affected by floor space allowance on: A) d 2, B) d 9, C) d 23, and D) d 51. GS = group size.

free cortisol concentrations at d 2 of treatment, as well as an increased farrowing rate. The biological relevance of the range of space allowances in the present experiment is demonstrated by these effects on aggression, stress, and reproduction. Even though space affected aggression and cortisol at d 2, there was no evidence that space affected aggression at d 8 or plasma total and free cortisol concentrations at d 9 and 51 of the experiment.

Previous experiments have shown effects of space on aggression, and stress in grouped female pigs. Both Weng et al. (1998) and Remience et al. (2008) have shown that reduced space increases sow aggression. Weng et al. (1998) found that the numbers of head interactions, including bites, as well as nose interactions with other sows, threats, and withdrawals at d 6 and 7 of treatment were generally higher at 2.0 m^2/sow than at 2.4, 3.6 and 4.8 m^2/sow. Although reciprocal aggressive behavior (bites or knocks) did not differ, Remience et al. (2008) found that nonreciprocal aggression at d 3 and 8 after mixing was higher at 2.25 m^2/sow than at 3.0 m^2/sow.

In addition to the evidence that free and total cortisol concentrations were generally increased at 9 to 11 and 67 to 76 d of treatment in gilts with a space allowance of 1.0 than 3.0 m^2/gilt and, at times, at 1.0 than 2.0 m^2/gilt (Hemsworth et al., 2006), free and total cortisol concentrations were increased at a space allowance of 1.0 m^2 than 1.4 or 2.0 m^2/gilt after 28 to 29 and 49 to 51 d of treatment (Barnett et al., 1992), and after 36 and 53 d of treatment (Barnett, 1997). In contrast, there was no relationship found between space and free and total cortisol concentrations at d 9 and 51 of treatment in the present experiment. There is no obvious explanation for these conflicting effects on cortisol concentrations, but sows that are more experienced with group housing may adapt more quickly to spatial restriction in groups than gilts.

The effects of space on aggression and stress in the present experiment were most pronounced early after grouping, suggesting that sows in static groups may adapt, either behaviorally or physiologically, over time to reduced space. It needs to be recognized that, because sows were removed from this experiment if they suffered reproductive failure, injury, or escaped from their pens, sufficient space may have been provided to reduce stress

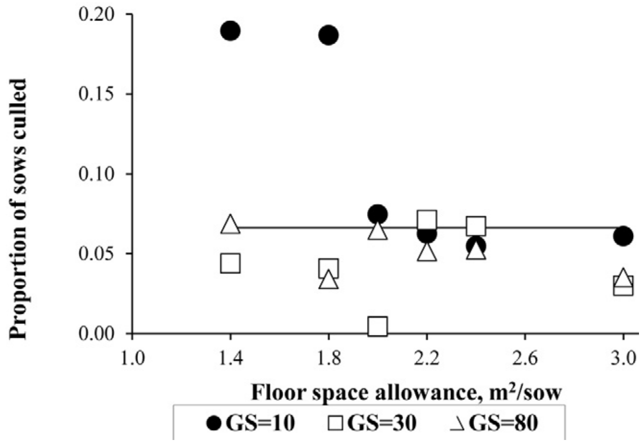

Figure 8. Predicted values of the proportion of sows culled for nonreproductive reasons as affected by floor space allowance. GS = group size.

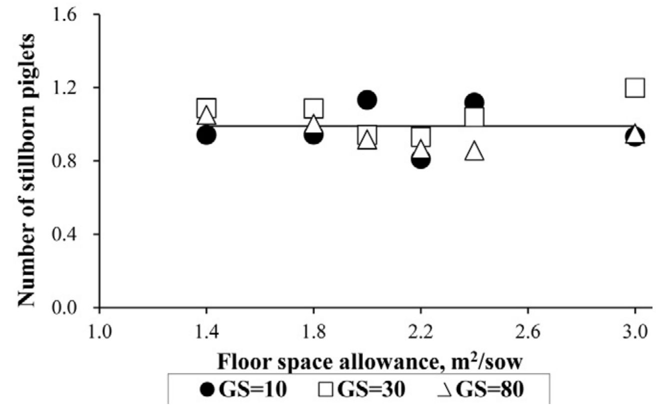

Figure 10. Predicted values of number of stillborns as affected by floor space allowance. GS = group size.

in pens with allocated low space allowances. However, less than 1% of sows were removed from the study before d 9. Furthermore, most sows were removed from the experiment for reproductive failure when confirmed not pregnant at 5 wk after insemination. If sows in the present experiment adapted over time to reduced space, the mechanism involved and the role of pregnancy in this are unknown. In rodents, there is evidence a dampening of the hypothalamo-pituitary-adrenal axis' response to stressors as gestation proceeds and during lactation (Lightman et al., 2001). Moreover, increasing density (increasing animals/unit of space) increased plasma corticosterone concentrations in male mice at d 1 and 7, but not at d 14, after grouping (Peng et al., 1989). Although the development of the social hierarchy over time may assist in reducing aggression and stress with overcrowding, habituation to spatial restriction may also be implicated. Apart from a few studies similar to Peng et al. (1989), there is little evidence in the literature of habituation to spatial restriction in groups. Clearly, there is a need to examine the effects of reducing space during gestation because this effect may offer the opportunity for staged-gestation penning to provide increased space immediately after insemination. Nevertheless, these results highlight the importance of sufficient space to reduce aggression and stress at mixing, and that the sow's requirement for space appears to be less once the group is well established.

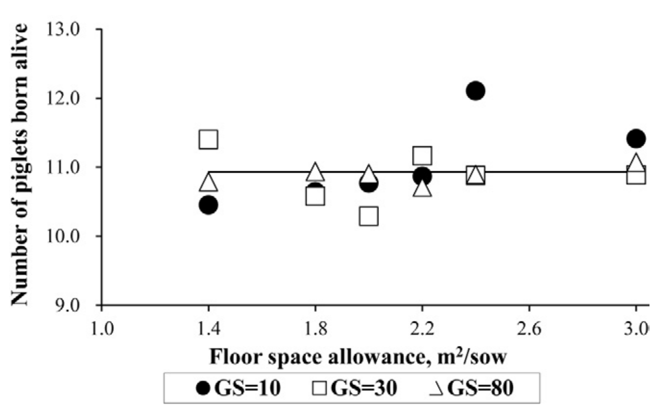

Figure 9. Predicted values of litter size (born alive) as affected by floor space allowance. GS = group size.

There was little or no effect of space on fresh or total skin injuries at d 2, 9, 23, and 51 of treatment in the present experiment. Several other studies have shown similar effects of space on both aggression and stress, but also no effects on skin injuries (Barnett et al., 1992, 1993; Barnett, 1997). For example, Barnett et al. (1992) found that both aggression and cortisol concentrations were higher at a floor space of 1.0 than 2.0 m^2/gilt, but no effect of space on skin injuries in gilts in groups of 4 at d 10 of treatment. However, Weng et al. (1998) found that fresh skin injuries (cuts and scratches) in sows in groups of 6 at d 7 were greater at 2.0 than 2.4 m^2/sow, which in turn were greater than in 3.6 and 4.8 m^2/sow. Furthermore, Salak-Johnson et al. (2007) observed that sows in groups of 5 at a space allowance of 1.4 m^2/sow had consistently higher lesion scores than those at 2.3 or 3.3 m^2/sow. Remience et al. (2008) found that fresh superficial and deep skin injuries were higher at wk 1 and 2 and wk 1 after grouping in dynamic groups of sows provided with 2.25 than 3.0 m^2/sow.

There are several differences between these 3 previous experiments and the present one. In the studies by Weng et al. (1998) and Salak-Johnson et al. (2007), sows were introduced to their treatments at 7 to 10 wk and 25 d postinsemination, respectively, which are stages of pregnancy when aggression at mixing may be lower than when mixed earlier (Hemsworth et al., 2006). Salak-Johnson et al. (2007) studied sows that were mixed once confirmed pregnant and floor fed, and Weng et al. (1998) studied pregnant sows in established groups that were housed for 1 wk in each of 4 space allowances in a Latin-square design and were confined for 1 h daily in stalls at feeding. Remience et al. (2008) examined sows in 2 dynamic groups in which a third of the 34 sows in a group were replaced every 5 wk and feed was provided in an electronic sow feeder system.

In summary, even though there are some differences in the results of the previous and present experiments,

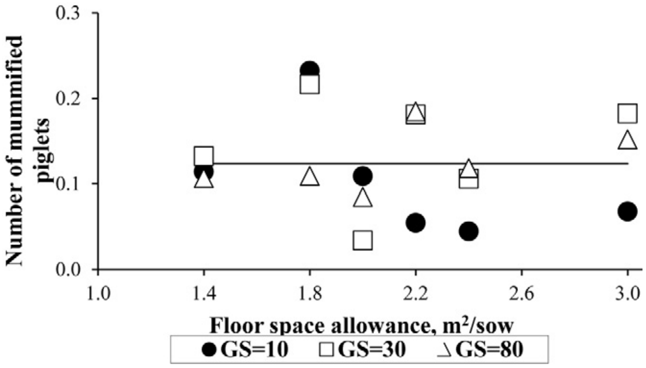

Figure 11. Predicted values of number of mummified pigs as affected by floor space allowance. GS = group size.

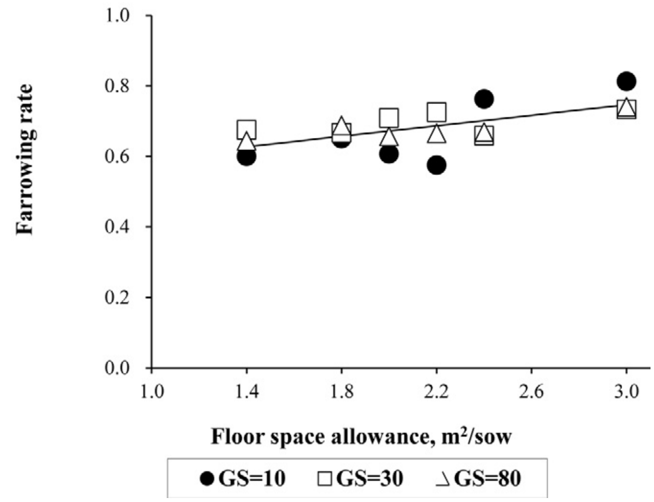

Figure 12. Predicted values of farrowing rate as affected by floor space allowance. GS = group size.

these results indicate that space can affect aggression, injuries, and stress physiology. The most striking difference between these studies was the effect of space on injuries, but the consequences of fighting on skin injuries may be reduced in relatively confined conditions.

The effects of space on farrowing rate were not unexpected, because there is evidence that stress postinsemination can adversely affect reproductive performance of sows. Although it is generally accepted that stress impairs reproduction, Turner et al. (2005) concluded that reproduction in female pigs is resistant to the effects of acute or repeated acute stress, even if these occur during the series of endocrine events that induce estrus and ovulation. In contrast, the authors concluded that prolonged stress and sustained increased cortisol can disrupt reproductive processes in female pigs, although a proportion of female pigs appear to be resistant to the effects of prolonged stress or sustained increased cortisol. In contrast to the present study, Salak-Johnson et al. (2007) reported no effects of floor space allowance on the reproductive performance of sows; however, sows were introduced to their treatments at 25 d postinsemination, a period in which complete reproductive failure is less likely (Ashworth and Pickard, 1998).

Even though aggression at d 2 of treatment was not affected by group size, the incidence of total skin injuries after d 2 was affected by group size in the present experiment. Groups of 10 had consistently low injuries from d 9 to 51, whereas the highest incidence of total injuries at d 9 and 23 was observed in groups of 30 and at d 51 in groups of 80. Locomotion and, thus, opportunity to slip or interact with other sows and pen features, may be less in small groups. Consequently, the risk of skin injuries could be reduced in small groups.

There is little information on the effects of group size on injuries in sows, and most of the studies on this topic are confounded by space allowance or feeding system. Taylor et al. (1997) reported that, although aggression on d 1 and 2 increased with increasing group sizes from 5 to 40 sows with a space allowance of 2.0 m^2/sow, the number of injuries on d 5 and 53 of treatment, as well as reproductive performance, was similar across treatments. Aggression is likely to lead to skin injuries (Turner et al., 2006), but contact with pen features associated with avoidance of other sows, particularly fast movement in large pens, may also increase the incidence of skin injuries (Karlen et al., 2007).

There were a number of other effects found in the present experiment that are difficult to interpret. There were relationships between group size and neutrophil-to-lymphocyte ratios at d 2 and 51, but not 9. At d 2 and 51, a low neutrophil-to-lymphocyte ratio was associated with a group size of 10, but, at d 9, a low neutrophil-to-lymphocyte ratio was associated with intermediate space allowances. Stressors can be deleterious to immune function, and studies in a number of species have shown that increasing corticosteroid concentrations result in a redistribution of white blood cells, in particular an increase in neutrophils, a decrease in lymphocytes, resulting in higher neutrophil-to-lymphocyte ratios (see Karlen et al., 2007). Even though group size was related to the neutrophil-to-lymphocyte ratios at d 2 and 51, there were no effects of group size on cortisol concentrations. In contrast, marked, or sustained changes in neutrophil and lymphocyte numbers are most common during fear, excitement, or strenuous exercise than with scratches and minor cuts (Smith, 2006).

Live weight gain was greatest in groups of 10 and backfat gain was highest in a floor space of 1.4 m^2/sow. Again, explanations for these relationships are not obvious. Sows in groups of 10 had consistently low injuries throughout the study and, thus, it is possible that these sows may have been more settled around feeding, allowing for less feed wastage and increased feed intake. The higher backfat gain in the groups with 1.4 m^2/sow is surprising, particularly because these sows had higher cortisol concentrations early in the experiment. However, Sargent (2001) found that ACTH-treated pigs had a higher feed intake, and were

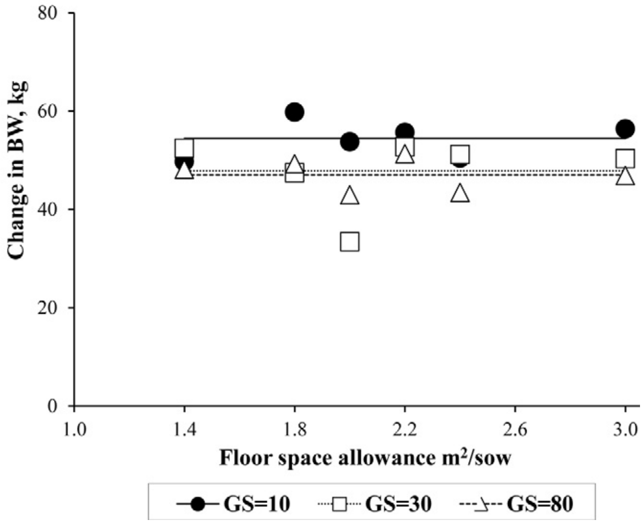

Figure 13. Predicted values of live BW change as affected by floor space allowance. GS = group size.

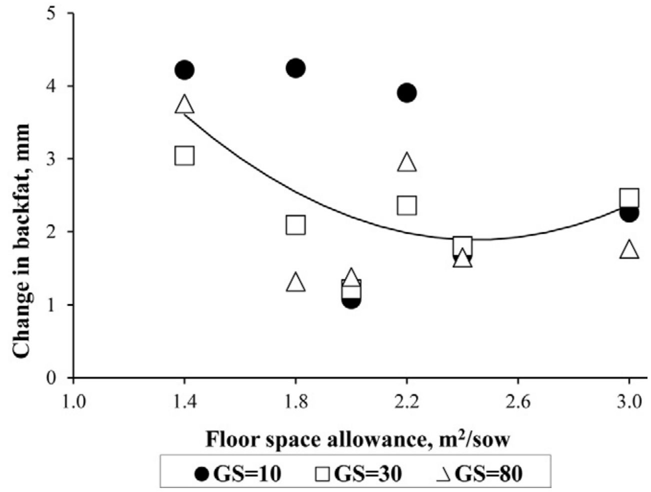

Figure 14. Predicted values of P2 backfat change as affected by floor space allowance. GS = group size.

fatter at the carcass P2 backfat and leg fat sites, with more visceral fat. Experiments conducted on broiler chickens (Bartov et al., 1980; Siegel and van Kampen, 1984) have shown that chronic treatment with corticosterone increased feed intake and fat deposition in the abdominal area. Moreover, Forbes (1995) administered corticosteroids to sheep and cattle, and noted increases in both carcass fatness and feed intake. Sows with reduced space in the present study had increased cortisol concentrations early in the study, and, perhaps, stress at this stage of reproduction may have affected fat deposition during gestation. In contrast, Salak-Johnson et al. (2007) observed that sows grouped 25 d postinsemination in pens at 1.4 m^2/sow had lower condition score, BW, and backfat throughout gestation than those in pens at 2.3 or 3.3 m^2/sow.

Although these effects of space early after grouping have sow productivity implications, interpreting the welfare implications is problematic. When relying on behavioral, physiological, and fitness measures to determine welfare risks, a judgment is made about what degree of change in these indicators is likely to indicate compromised sow welfare. Based on the effects of space on aggressive behavior, cortisol concentrations and farrowing rate, it is credible to judge that, within the range of floor space in this study, sow welfare improved as floor space allowance increased, a position supported by others (Barnett, 1997; Weng et al., 1998; Salak-Johnson et al., 2007).

The space allowance at which sow welfare, based on aggressive behavior and cortisol concentrations, is compromised is difficult to assess from the present results. Although the results are in accord with a linear decline in d 2 cortisol and aggression from 1.4 to 3 m^2/sow, the results are also in accord with a decline in cortisol and aggression from 1.4 to 1.8 m^2/sow, and no further decline above 1.8 m^2/sow. The size of the experiment has turned out to be insufficient to determine which of these scenarios is more biologically correct. Thus, in terms of animal welfare at mixing, it is impossible to provide guidance on an adequate space allowance, other than a space allowance of 1.4 m^2/sow is likely too small. And, even though group size had little or no effect on aggression, cortisol concentration, or reproduction, sows in groups of 10 generally had less injuries throughout the study, which is desirable from a welfare perspective.

An obvious question is the implications of the present results for group housing with other feeding systems. Conventional restricted feeding in group-housed sows increases hunger and, in turn, competition for feed or access to feeding areas (Barnett et al., 2001). While floor feeding is competitive, accessing feeding stalls or electronic sow feeder stalls also leads to competition between group-housed sows. For instance, in nongated stalls, aggression often occurs during feeding periods; and in electronic sow feeding systems, queuing and vulva biting occur in accessing feeding stalls (Bench et al., 2013). There is evidence that floor space in pens with feeding stalls affects aggression and stress. In a factorial experiment, feeding system (3 feeding arrangements: no stalls and fed on the floor, stalls and fed on the floor, or stalls and fed in stalls) and total floor space (2 allowances: 1.0, or 2.0 m^2/gilt) affected aggression at 2 to 15 d and cortisol concentrations at 28 to 29 and 49 to 51 d of treatment, but there were no interactions between feeding arrangement and space (Barnett et al., 1992). In a similarly designed experiment, feeding system (4 feeding arrangements: no stall, trough, trough with shoulder stall, or trough with body stall) and space outside the feeder (3 space allowances: 1.0, 1.4 or 2.0 m^2/gilt) both affected aggression at 2 to 54 d and cortisol concentrations on 36 and 53 d of treatment (Barnett, 1997). Thus, these results highlight the importance of floor space, irrespective of the feeding system.

Results of the present experiment indicate that the effects of space allowance were most pronounced early after grouping, and that sows in static groups may adapt to reduced space. Nevertheless, in terms of risks to both welfare and productivity, these results highlight the need to reduce aggression and stress at mixing. Clearly, further research is required to examine the effects of space allowance in the range of 1.8 to 2.4 m^2/sow in more detail, with particular attention given to the effects of space early postinsemination because this is the period when effects on aggression, stress, and reproduction are likely to be most pronounced.

LITERATURE CITED

Arey, D. S., and S. A. Edwards. 1998. Factors affecting aggression between sows after mixing and the consequences for welfare and production. Livest. Prod. Sci. 56:61–70.

Ashworth, C. J., and A. R. Pickard. 1998. Embryo survival and prolificacy. In: J. Wiseman, M. A. Varley, and J. P. Chadwick, editors, Progress in pig science. Nottingham Univ. Press, UK. p. 303–325.

Barnett, J. L. 1997. Modifying the design of group pens with individual feeding places affects the welfare of pigs. In: R. W. Bottcher and S. J. Hoff, editors, Livestock Environment V, Volume II. Proc. 5th Int. Symp. American Soc. Agric. Engin., Bloomingham, MI. p. 613–618.

Barnett, J. L., G. M. Cronin, T. H. McCallum, and E. A. Newman. 1993. Effects of pen size/shape and design on aggression when grouping unfamiliar adult pigs. Appl. Anim. Behav. Sci. 36:111–122.

Barnett, J. L., P. H. Hemsworth, G. M. Cronin, E. C. Jongman, and G. D. Hutson. 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., P. H. Hemsworth, G. M. Cronin, E. A. Newman, T. H. McCallum, and D. Chilton. 1992. Effects of pen size, partial stalls and method of feeding on welfare-related behavioural and physiological responses of group-housed pigs. Appl. Anim. Behav. Sci. 34:207–220.

Bartov, I., L. S. Jensen, and J. R. Veltman. 1980. Effects of corticosterone and prolactin on fattening in broiler chickens. Poult. Sci. 59:1328–1334.

Bench, C. J., F. C. Rioja-Lang, S. M. Hayne, and H. W. Gonyou. 2013. Group gestation housing with individual feeding—I: How feeding regime, resource allocation, and genetic factors affect sow welfare. Livest. Sci. 152(2):208–217.

Bocking, A. D., I. C. McMillen, R. Harding, and G. D. Thorburn. 1986. Effect of reduced uterine blood flow on fetal and maternal cortisol. J. Dev. Physiol. 8:237–245.

Broom, D. M., and K. G. Johnson. 1993. Stress and animal welfare. Chapman and Hall, London.

Forbes, J. M. 1995. Voluntary food intake and diet selection in farm animals. CAB International, Wallingford, UK.

Fraser, D. 2008. Understanding animal welfare: The science in its cultural context. Wiley-Blackwell, West Sussex, UK.

Hemsworth, P. H., B. H. Stevens, R. Morrison, G. M. Karlen, A. D. Strom, and H. W. Gonyou. 2006. Behaviour and stress physiology of gestating sows in a combination of stall and group housing. In: Proc. 40th Int. Congr. ISAE, Bristol, UK. p. 11.

Karlen, G. A., P. H. Hemsworth, H. W. Gonyou, E. Fabrega, D. Strom, and R. J. Smits. 2007. The welfare of gestating sows in conventional stalls and large groups on deep litter. Appl. Anim. Behav. Sci. 105:87–101.

Lightman, S. L., R. J. Windle, S. A. Wood, Y. M. Kershaw, N. Shanks, and C. D. Ingram. 2001. Peripartum plasticity within the hypothalamo-pituitary-adrenal axis. Prog. Brain Res. 133:111–129.

Olsson, A. C., J. Svendsen, and D. Reese. 1994. Housing of gestating sows in long narrow pens with liquid feeding: Function studies and grouping routines in five sow pools. Swed. J. Agric. Res. 24:131–141.

Peng, X., C. M. Lang, C. K. Drozdowicz, and B. M. Ohlsson-Wilhelm. 1989. Effect of cage population density on plasma corticosterone and peripheral lymphocyte populations of laboratory mice. Lab. Anim. 23:302–306.

Remience, V., J. Wavreille, B. Canart, M. Meunier-Salaun, A. Prunier, N. Bartiaux-Thrill, B. Nicks, and M. Vandenheede. 2008. Effects of dry space allowance on the welfare of dry sows kept in dynamic groups and fed with an electronic sow feeder. Appl. Anim. Behav. Sci. 112:284–296.

Salak-Johnson, J. L., S. R. Niekamp, S. L. Rodriguez-Zas, M. Ellis, and S. E. Curtis. 2007. Space allowance for dry, pregnant sows in pens: Body condition, skin lesions and performance. J. Anim. Sci. 85:1758–1769.

Sargent, R. 2001. The social and feeding behaviour of growing pigs in deep-litter, group housing systems. Ph.D. Diss. University of Melbourne, Parkville, VIC, Australia.

Siegel, H. S., and M. van Kampen. 1984. Energy relationships in growing chickens given daily injections of corticosterone. Br. Poult. Sci. 25:477–485.

Smith, G. S. 2006. Neutrophils. In: B. F. Feldman, J. G. Zinkl, and N. C. Jain, editors, Schalm's Veterinary Hematology. Blackwell Publishing Asia, Carlton, VIC, Australia. p. 261–412.

Taylor, I. A., J. L. Barnett, and G. M. Cronin. 1997. Optimum group size for pigs. In: R. W. Bottcher and S. J. Hoff, editors, Livestock Environment V, Volume II. Proc. 5th Int. Symp. American Soc. Agric. Engin., Bloomingham, Michigan. Am. Soc. of Agricultural Engineers, St. Joseph, MI. p. 965–971.

Turner, S. P., M. J. Farnworth, I. M. S. White, S. Brotherstone, M. Mendl, P. Knap, P. Penny, and A. B. Lawrence. 2006. The accumulation of skin lesions and their use as a predictor of individual aggressiveness in pigs. Appl. Anim. Behav. Sci. 96:245–259.

Turner, A. I., P. H. Hemsworth, and A. J. Tilbrook. 2005. Susceptibility of reproduction in female pigs to impairment by stress or elevation of cortisol. Domest. Anim. Endocrinol. 29:398–410.

Verlarde, A. 2007. Agonistic behaviour. In: A. Verlarde and R. Geers, editors, On farm monitoring of pig welfare. Wageningen Academic Press, Wageningen, the Netherlands. p. 53–56.

Weng, R. C., S. A. Edwards, and P. R. English. 1998. Behaviour, social interactions and lesion score of group-housed sows in relation to floor space allowance. Appl. Anim. Behav. Sci. 59:307–316.