Effects of housing finishing pigs in two group sizes and at two floor space allocations on production, health, behavior, and physiological variables[1]

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ABSTRACT: With the current shift in the industry toward housing pigs in groups of 100 to 1,000 per pen have come questions as to whether pigs can perform as well in large groups as they do in small and whether large groups of pigs can use the space provided more efficiently. This study examined effects of small (18 pigs) vs. large (108 pigs) group sizes provided 0.52 m^2/pig (crowded) or 0.78 m^2/pig (uncrowded) of space on production, health, behavior, and physiological variables. Eight 7-to 8-wk-long blocks, each involving 288 pigs, were completed. The average BW at the beginning of the study was 37.4 ± 0.26 kg. Overall, ADG was 1.032 kg/d and 1.077 (±0.015) kg/d for crowded and uncrowded pigs, respectively (P = 0.018). Differences between the space allowance treatments were most evident during the final week of study. Overall G:F was also reduced (P = 0.002) in the crowded treatment. Pigs in the crowded groups spent less (P = 0.003) time eating over the 8-wk study than did pigs in noncrowded groups, but ADFI did not differ (P = 0.34) between treatments. Overall, ADG of large-group pigs was 1.035 kg/d, whereas small group pigs gained 1.073 kg/d (±0.015; P = 0.039). Average daily gain differences between the group sizes were most evident during the first 2 wk of the study. Over the entire study, G:F also differed, with large groups being less efficient (P = 0.005) than small groups. Although large-group pigs had poorer scores for lameness (P = 0.012) and leg scores (P = 0.02) throughout the 8-wk period, morbidity levels did not differ (P = 0.32) between the group sizes. Minimal changes in postural behavior and feeding patterns were noted in large groups. An interaction (P = 0.04) of group size and space allowance for lameness indicated that pigs housed in large groups at restricted space allowances were more susceptible to lameness. Although some behavioral variables, such as lying postures, suggest that pigs in large groups were able to use space more efficiently, overall productivity and health variables indicate that pigs in large and small groups were similarly affected by the crowding imposed in this study. Broken-line analysis of ADG indicated no difference in the response to crowding by pigs in large and small groups. Little support was found for reducing space allowances for pigs in large groups.

Key words: pigs, behavior, group size, health, productivity, space allowance

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INTRODUCTION

With the shift in hog operations to housing pigs in large groups of over 100 per pen, questions have arisen as to how these pigs should be managed. Pigs in large groups have been suggested to more efficiently use space in crowded conditions, because the free space available to all pigs is greater (McGlone and Newby, 1994). McGlone and Newby (1994) also hypothesized that space could be reduced in large groups without negatively affecting production. However, a study in a strawed system did not find such an interaction (Turner et al., 2000), and studies in nonbedded systems have not provided identical space allowances to both large and small groups (McGlone and Newby, 1994; Wolter et al., 2000).

Space recommendations put forth by AAFC (1993) have been based on traditional group sizes, which tend to range from 10 to 40 pigs per pen. Therefore, this study was designed to assess space requirements of both large (108 pigs) and small (18 pigs) groups and crowded and uncrowded groups of pigs with the objective of determining the critical point at which gains are

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affected by reduced floor space in each group size and the rate at which this depression in gains occurs. Space allowances have been expressed using a space coefficient (k) derived from the allometric equation area = $k \times BW^{0.667}$, where area is in meters squared and BW is in kilograms. Gonyou et al. (2006) identified the critical value, or point at which production begins to decline due to space restriction, at $k = 0.034$. We used this value as a basis for differentiating the crowded and uncrowded treatments. Effects of group size and space allowance on pig performance, behavior, physiology, and health over time were examined in this study.

MATERIALS AND METHODS

Animals and Feeding

This project was approved by the University Committee on Animal Care and Supply of the University of Saskatchewan, which is subject to the Canadian Council on Animal Care.

Two thousand three hundred four pigs (Pig Improvement Company, Hendersonville, TN, maternal line C22 or C42, paternal line 337), in 8 blocks consisting of 288 pigs each, were utilized in a study of group size and space allowance. The first 2 blocks were a multisex experiment examining only productivity, injuries, and health. The remaining 6 blocks used only barrows and examined behavior and physiological variables in addition to production, injuries, and health. Pigs entered the grow-finish area of the barn at 10 to 11 wk of age after being housed in groups of 14 to 20 pigs/pen in the nursery from 3 wk of age. They were randomly allocated to treatments at this time and were then allowed a 3- or 4-d habituation period before the first weighing. At this time, pigs were an average of 37.4 ± 0.26 kg of BW.

Nutritionally balanced mash diets, based on NRC requirements (NRC, 1998), were fed to the pigs in 3 phases according to their stage of growth. Feed was supplied via an automated feed system and was measured before entry into the feeder by means of calibrated weight-based dump scales (Brehmer Manufacturing, Lyons, NE). Feed and water were supplied ad libitum in 2-space (back-to-back single space) wet-dry feeders (Crystal Springs, St. Agathe, MN), which were provided at a rate of 1 space (32-cm width) for every 9 pigs. Water was not provided elsewhere. In the large groups, all 6 feeders (12 feeding spaces) were contiguous near 1 end of the pen and arranged to provide 2 back-to-back rows of 6 spaces each. In adjacent small groups, the feeders were side by side and filled by a single dump scale.

Pigs were housed on fully slatted flooring. Pen partitions were spindled, but penning along the central alleyway was made of solid interlocking polyvinyl chloride panels. Room ventilation was thermostatically controlled to maintain thermoneutral temperatures, except during weather exceeding 25°C. Lighting was kept on a consistent 12:12 bright:dim cycle to allow for behavioral observations at night. Environmental enrichment in the form of Bite rite devices (AM Warkup Ltd., Lisset, UK) was provided at a rate of 1 device for every 18 pigs.

Treatments

In each block, there were 4 experimental treatments in a 2×2 factorial arrangement: small crowded (2 pens of 18 pigs at 0.52 m^2/pig), small uncrowded (2 pens of 18 pigs at 0.78 m^2/pig), large crowded (108 pigs at 0.52 m^2/pig), and large uncrowded (108 pigs at 0.78 m^2/pig). Pen dimensions were approximately 5.8×1.6 m, 5.8×2.4 m, 9.8×5.8 m, and 14.6×5.8 m for small crowded, small uncrowded, large crowded, and large uncrowded, respectively. Although the space allowance coefficient (k where k = area/$BW^{0.667}$, see Petherick, 1983, or Gonyou et al., 2006) decreased as the pigs grew, the floor space allowance for the uncrowded treatment remained above the critical value $k_{UC} = 0.034$ throughout the study. For the crowded treatment, the space allowance chosen provided $k_C = 0.035$ at an average of 55 kg of BW; $k_C = 0.028$ at 75 kg of BW; and $k_C = 0.025$ at 95 kg of BW. Previously established animal care guidelines were set to terminate the crowded treatment at $k_C = 0.025$.

Procedures

Productivity and Health. Pigs were weighed on a weekly basis to obtain an average pen weight, which could then be used to calculate ADG at weekly intervals. Feed additions were recorded daily to calculate weekly feed consumption and G:F.

Every 2 wk and at the same time as weighing, the pigs were assessed for injuries, including tail bites (pigs had been docked), flank bites, leg lesions, and lameness. Scores began at zero (no injury present) and increased with increasing severity (Table 1). Twice daily walk-through health assessments were conducted to maintain accurate morbidity and mortality records.

Behavioral Time Budgets and Feeding Patterns. Behavioral observations employed methodology described by Martin and Bateson (2003) and were carried out at 2-wk intervals. Instantaneous scan sampling of each pen within 20-min intervals throughout a 24-h period was performed to determine the number of pigs that were lying laterally (on side), lying ventrally (sternum in contact with floor), sitting (supported by 2 legs; resting on rump), standing (supported on 4 legs but not eating), and eating (head in the feeder). Data were expressed as a percentage of time.

To examine frequency and duration of feeding events, as well as latency between meals, video cameras monitored groups of feeders continuously for a 24-h period every 2 wk throughout the study. Data were recorded using a time-lapse VCR (Panasonic AG6730 or AGTL950, Mississauga, Ontario, Canada). Eight pigs from each treatment combination were randomly selected and individually identified as focal pigs by use

Table 1. List of injury scores and their corresponding meanings

Injury and score	Meaning
Flank bite	
0	No injury present
1	Hair is worn off of area
2	Redness or inflammation present
3	Outer layer of skin has been removed
4	Scabbing has formed over the wound
5	Severe wound, inflammation surrounding the area
Tail bite	
0	No injury present
1	Minimal injury but signs of chewing visible
2	Visible blood from open wound
3	Outer layer of skin removed
4	Severe swelling and redness or tail necrosis
Lameness	
0	No injury present
1	Leg is swollen and red; pig does not favor the leg
2	Pig does not bear full weight on leg but puts foot down
3	Pig avoids putting the foot down
Leg lesion	
0	No injury present
1	Swollen joint is visible
2	Abscess visible on joint
3	Beginning formation of a small open wound
4	Scabbing has formed over the wound
5	Large open wound is present
Leg bursa	
No	No bursa present
Yes	Presence of 1 or both leg bursa on olecranon joint

of a colored, numbered ear tag on the day they entered the grow-finish room. These pigs were identified by paint markings before each videotaping session. Only eating data obtained for the focal pigs were analyzed. An interval analysis of daily eating bouts was conducted using the plot technique to establish a bout criterion for actual meals (Lehner, 1979). A bout criterion interval of 6 min was used to define meals. Shorter interruptions in eating were considered to be within a meal.

Physiological Measurements. Saliva samples were taken from the focal pigs at 2-wk intervals throughout the study. Sampling took place from 1200 to 1400 to reduce diurnal variation in cortisol concentrations. Samples were collected using an absorbent cotton wad held close to the mouth of the pig manually or on a stick. The pig was allowed to chew the cotton wad until it was saturated with saliva. Sampling was attempted for no more than 2 min per pig. Within sampling periods, all samples obtained from a pen in less than 5 min were combined (equal volumes) to obtain a single pen sample for analysis. All samples from the first sampling period, however, were analyzed individually and then averaged. Saliva samples were analyzed for salivary cortisol concentrations using a competitive enzyme immunoassay described by Cook et al. (1997). The intraassay CV were 15.6, 8.8, and 14.8%.

The left adrenal gland, which is morphologically more amenable to cross-sectional analysis than is the right, was collected at slaughter from 2 randomly selected focal pigs from each treatment within a block. The gland was trimmed of connective tissue, weighed, and used in further analyses. The gland was cross-sectioned in the midsection and stained with Grimelius stain (Sheehan and Hrapchak, 1980) so the areas of the cortex, medulla, and the total area could be measured and so the cortex:medulla and cortex:total ratios could be calculated. A left gland weight:100 kg of BW ratio was calculated for use in further analysis.

Statistical Analysis

The SAS system (SAS Inst. Inc., Cary, NC) was used for data analysis. Residuals were tested for normality, and data were transformed when necessary. In all cases, effects of group size, floor space allowance, and the interaction were tested using the pen as the experimental unit for large groups and the 2 adjacent small pens (fed from the same feeder) as the experimental unit for small groups. Initial (d 3) and final BW and the corresponding CV were tested using the GLM procedure. Productivity data (ADG, ADFI, G:F) and injury scores were analyzed using the MIXED procedure of SAS with week as a subplot. Pigs in blocks 1 and 2 were only weighed and scored for injuries at the beginning and end of the study. Therefore, only initial and final BW and injury score data were available for analysis from those blocks. Broken-line analyses (Robbins, 1986) were conducted on the ADG data to estimate the point at which crowding affected growth in both small and large groups. Average daily gain and the space coefficient (k at the end of the 3-wk period) were calculated for the first and final 3-wk periods for each experimental unit. Within each block, and within group size treatments, the uncrowded ADG was expressed as 100% and that of the crowded treatment was expressed as a proportion of that value. The increase in sums of squares explained by using separate analyses on large and small groups, vs. that explained by a combined analysis was tested for significance.

Feeding patterns and postural behavior were analyzed using the MIXED procedure of SAS with week as a sublot and, in the case of postural behaviors only, time of day as a sub subplot. For postural behavior, time budgets were averaged into 3-h periods in a day. Morbidity data were analyzed using the GENMOD procedure of SAS. Adrenal gland data were analyzed using the GLM procedure of SAS. Salivary cortisol concentration data were not normally distributed and were not able to be transformed into normally distributed values. Therefore, we compared means of the treatment combinations within each testing week using the Friedman 2-way ANOVA, a nonparametric test (Lehner, 1979). Neither behavioral nor physiological data were collected from the pigs in blocks 1 and 2, because it was a production-based study only. When individual animal data were available from blocks 1 and 2, sex was treated as a subplot within the treatment. Sex of pig data for

Table 2. Overall productivity, injury score, and health data of grow-finish pigs housed in large or small groups and at crowded or uncrowded space allowances

	Space allowance[1]		Group size[2]			*P*-value	
Item	UC	C	S	L	SEM	Space	Group size
Experimental units, n	16	16	16	16	—	—	—
Initial BW,[3] kg	37.28	37.50	38.02	36.76	0.26	0.57	0.003
$CV_{initial\ BW}$	16.23	16.73	16.69	16.27	0.59	0.56	0.62
Final BW, kg	94.65	92.62	95.08	92.20	0.41	0.002	<0.0001
$CV_{final\ BW}$	11.27	11.26	11.43	11.10	0.36	>0.95	0.52
Overall ADG, kg/d	1.077	1.032	1.073	1.035	0.015	0.018	0.039
Overall ADFI, kg/d	2.774	2.834	2.824	2.783	0.049	0.34	0.51
Overall G:F	0.3958	0.3697	0.3945	0.3710	0.0055	0.002	0.005
Injury scores[4]							
Lameness	0.025	0.024	0.019	0.030	NA	0.65	0.012
Flank bites	0.034	0.044	0.036	0.041	NA	>0.95	0.27
Tail bites	0.038	0.047	0.054	0.031	NA	0.69	0.41
Leg lesion	0.140	0.154	0.128	0.166	NA	0.80	0.020
Received medication, %							
Lameness	3.73	6.08	4.34	5.09	0.23	0.53	0.51
Other[5]	2.69	3.13	2.26	3.13	0.18	0.87	0.30
Total	6.42	9.20	6.60	8.22	0.24	0.64	0.14
Removed, %							
Lameness	0.96	1.65	0.87	1.45	0.15	0.25	0.21
Tail bitten	1.04	0.61	1.04	0.75	0.25	0.58	0.63
Other[5]	1.30	2.08	1.22	1.85	0.15	0.17	0.34
Total	3.30	4.34	3.13	4.05	0.19	0.21	0.32

[1]UC = uncrowded (0.78 m^2/pig); C = crowded (0.52 m^2/pig). Space allowance × group size interactions were nonsignificant ($P > 0.05$) with the exception of lameness ($P = 0.04$).

[2]S = small (18 pigs); L = large (108 pigs).

[3]Taken after a habituation period of 3 to 4 d.

[4]Blocks 1 and 2 were only scored the day they began the test and the day they ended the test phase. Pigs in other blocks were scored at 2-wk intervals. Greater scores indicate more severe injury. Raw data means, SEM not applicable; *P*-values derived from analysis of the square root transformation of raw data.

[5]Includes mortalities, open wounds, abscess, hernia, rash, prolapse, coughing, and unthriftiness.

blocks 1 and 2 were analyzed using the GLM procedure of SAS.

RESULTS

Productivity and Health

Productivity. Interactions of group size and space allowance were not evident ($P > 0.05$) for any of the performance parameters (ADG, ADFI, G:F). Overall productivity of crowded and uncrowded pigs is illustrated in Table 2. Overall ADG and G:F were affected by space allowance, but ADFI was not. Crowded pigs gained 4.2% less than uncrowded pigs overall and were 6.6% less efficient. Final BW were 2.1% lower among crowded pigs than uncrowded pigs. Average daily gain and G:F were most affected by space allowance during the final week of the study (95 kg of BW; $k = 0.025$). At that time, gains of the uncrowded pigs exceeded that of crowded pigs by 9.8% (1.067 vs. 0.962 ± 0.035 kg/d; $P = 0.028$), and G:F of uncrowded pigs exceeded that of crowded pigs by 11% (0.356 vs. 0.316 ± 0.011; $P = 0.008$).

Overall productivity of pigs in large and small groups is shown in Table 2. Over the study, pigs in the small group gained 3.5% more than those in large groups, resulting in a final BW differences of 3.0%. Average daily gain was most affected by group size in the first 2 wk of the study (1.083 vs. 1.024 ± 0.013 kg/d for small and large groups, respectively; $P = 0.005$). The initial BW, determined 3 to 4 d after allotment to treatments, were found to be 3.3% lower in large groups than in small. This could be due either to chance during the allocation process or to poor performance during those first few days in the large groups. Overall, pigs in small groups also had 6.0% greater G:F, and the difference was most noticeable during the final week of the study, at which point pigs housed in small groups were 14% more efficient than those housed in the large groups (0.360 vs. 0.313 ± 0.011; $P = 0.004$).

According to the broken-line analysis, the critical k value for pigs in small groups was $k = 0.035$ (approximately 57 kg of BW). For $k > 0.035$, then ADG (% of uncrowded) = 100; for $k < 0.035$, then ADG = $1086.2k + 62.121$ ($R^2 = 0.348$; $P = 0.026$). For every 1% decrease in space below the critical value in the small groups, gains were depressed by 0.4%. The large group-housed pigs showed reduced gains at $k = 0.039$ (approximately 49 kg of BW). For $k > 0.039$, then ADG = 100; for $k < 0.039$, then ADG = $662.8k + 74.31$ ($R^2 = 0.495$; $P < 0.001$). For every 1% decrease in space below the critical value in the large groups, gains were depressed by 0.3%. However, the variation explained by using separate response lines for small and large groups was not significant ($F_{1,18} = 0.20$; $P > 0.10$), indicating the response to crowding did not differ between group sizes. For the combined data, the break point was $k = 0.036$ and for $k < 0.036$, ADG = $899.8k + 67.4\%$ of the uncrowded treatment. In the final week of the study, ADG of the large and small crowded groups were nearly identical (0.963 vs. 0.962 kg/d), and the interaction of group size and crowding remained nonsignificant ($P = 0.13$).

Injuries. Overall injury data are shown in Table 2. Injury scores represent an average of all of the scores of the pigs within the treatment. Overall injury scores were not affected by space allowance, although the occurrence of leg lesions was greater among crowded pigs than uncrowded pigs at the final scoring period (0.41 vs. 0.27 ± 0.14; $P = 0.045$; $k = 0.025$).

Pigs housed in large groups experienced a greater overall incidence of lameness and leg lesions than pigs in small groups (Table 2). Large groups had greater lameness scores than small groups during the second scoring week (0.0204 vs. 0.0052 ± 0.0084; $P = 0.043$; 50 kg of BW) and during the final scoring week (0.055 vs. 0.036 ± 0.013, $P = 0.011$; 95 kg BW) as well. Leg lesion scores were also greater among large-group pigs during the second week (0.081 vs. 0.032 ± 0.024; $P = 0.005$; 50 kg of BW).

Interactions of group size and space allowance were evident for lameness only. Crowding resulted in greater lameness scores in large groups but reduced scores in small groups (0.037, 0.022, 0.010, and 0.027 ± 0.037 for large crowded, large uncrowded, small crowded, and small uncrowded, respectively; $P = 0.04$). A similar interaction pattern was evident at the second scoring period (0.036, 0.005, 0.003, and 0.013 ± 0.011; $P = 0.049$; 50 kg of BW; $k_C = 0.038$; $k_{UC} = 0.057$) and final scoring period (0.061, 0.049, 0.021, and 0.050 ± 0.016; $P = 0.043$; 95 kg of BW; $k_C = 0.025$; $k_{UC} = 0.037$).

Morbidity and Mortality. Overall morbidity data are shown in Table 2. No effects of space allowance or group size were found ($P > 0.05$) on the proportion of animals receiving medication for a health problem or the proportion of animals that had to be removed from the trial due to illness or death. Similarly, there were no interaction effects ($P > 0.05$) of group size and space allowance for the proportion of animals receiving medication or for the number of animals removed from the trial. The total mortality rate within the study was 0.9%. Mortality incidences were too low to differentiate among treatments.

Postural and Feeding Behavior

Behavioral Time Budgets (Scan Sampling). As pigs grew, the overall proportion of time they spent eating, standing, and lying ventrally in a 24-h period decreased. The proportion of time spent eating decreased from 6.89% during the first observation to 4.95% during the last (fourth) observation (±0.29 %; $P < 0.001$). The proportion of time spent standing decreased from 11.10% of time during the first observation to 6.07% in the last observation (±0.57 %; $P < 0.0001$). Pigs spent 24.5% of their time lying ventrally in the first observation compared with 20.0% of their time in that posture during the last observation (±1.0%; $P < 0.001$). The overall proportion of time the pigs spent lying laterally increased over time, from 54.9% in the first observation period to 65.7% in the last observation period (±1.4%; $P < 0.001$). The proportion of time spent sitting was similar over time ($P > 0.05$).

Behavioral time budgets for each treatment combination are shown in Table 3. Group size × space allowance interactions were seen for eating and sitting behaviors only. A reduction in eating due to crowding was only observed in the small groups, and crowding reduced sitting in small groups but increased it in large groups. Pigs in small groups spent more time lying ventrally and less time lying laterally than pigs in large groups.

Behavioral time budgets broken down into time of day were reported in eight 3-h segments (2-h observation and 1-h break). Pigs spent the majority of the time eating from 0700 to 1800, with the greatest proportion of time spent eating occurring from 1600 to 1800 (Figure 1a). Eating behavior decreased in the late evening and early morning hours, from 1900 to 2400 and from 0100 to 0600. Standing behavior peaked during the midafternoon hours of 1300 to 1500 (Figure 1b). Pigs spent less time standing from 0700 to 1200, but the least time spent standing occurred in the late evening and early morning hours, from 1900 to 2400 and from 0100 to 0600. Sitting behavior followed a very similar pattern to standing behavior, although the percentage of time spent sitting during any time period was less than that spent standing in the corresponding period. Because standing and sitting behavior patterns were very similar, only standing behavior is presented in Figure 1. Ventral lying followed a pattern similar to those for standing, sitting, and eating. Pigs spent the most time lying ventrally from 0700 to 1800, and the behavior peaked from 1600 to 1800 (Figure 1c). The least proportion of time spent lying ventrally occurred in the late evening and early morning hours, from 1900 to 2400 and from 0100 to 0600. Lateral lying followed a pattern opposite to the previously mentioned behaviors. This posture was assumed most frequently from 1900 to 0300, peaking from 0100 to 0300 (Figure 1d). From 1300 to 1800, lateral lying occurred the least. Intermediate values for lateral lying behavior fell from 0700 to 1200.

Space allowance and group size also had effects on certain behaviors within a particular time of day. Uncrowded pigs spent more time standing from 1000 to 1200 and from 1300 to 1500 than crowded pigs (Figure 2b). Crowded pigs spent more time lying laterally from 0100 to 0300 and from 1300 to 1500 than uncrowded pigs (Figure 2c). Pigs housed in small groups spent a greater proportion of their time sitting than pigs housed in large groups during all periods observed from 0700 to 1800 (Figure 2a). There were no group size × space allowance interactions ($P > 0.05$) for any behavior within any of the time periods observed.

Table 3. Overall behavioral time budgets of grow-finish pigs housed in large or small groups and at crowded or uncrowded space allowances

	Treatments[1]					*P*-values		
Item	SUC	SC	LUC	LC	SEM	Space (SP)	Group size (GS)	GS × SP
Experimental units,[2] n	6	6	6	6	—	—	—	—
Behavior,[3] % of day								
Eating	6.33[a]	5.04[c]	5.75[b]	5.71[b]	0.27	0.003	0.83	0.005
Standing	7.42	7.63	9.13	7.63	0.56	0.16	0.07	0.07
Sitting	3.54[a]	3.00[ab]	2.25[c]	2.71[bc]	0.23	0.85	0.003	0.041
Lying ventrally	23.50	23.54	21.50	20.63	0.89	0.54	0.002	0.50
Lying laterally	59.2	60.5	61.3	63.4	1.4	0.07	0.012	0.69

[a–c]Means within a row that do not have a common superscript letter differ ($P < 0.05$).

[1]SUC = small uncrowded (18 pigs, 0.78 m^2/pig); SC = small crowded (18 pigs, 0.52 m^2/pig); LUC = large uncrowded (108 pigs, 0.78 m^2/pig); LC = large crowded (108 pigs, 0.52 m^2/pig).

[2]Blocks 1 and 2 were not observed, so data has been analyzed from blocks 3 to 8 only. The experimental unit for small group treatments was 2 adjacent pens.

[3]Values are expressed as a percentage of a 24-h period.

Feeding Patterns (Continuous Observations). Overall, space allowance did not affect ($P > 0.05$) feeding patterns. However, during the final (fourth) observation (BW = 95 kg; $k_C = 0.025$; $k_{UC} = 0.037$), the mean number of meals eaten by pigs in the crowded groups was lower than the number eaten by the uncrowded groups (8.71 vs. 10.94 ± 0.79; $P = 0.012$). During that time, the total meal duration of crowded pigs was less than that of the uncrowded pigs (49.3 vs. 59.7 ± 3.3 min/24 h; $P = 0.024$), and the mean latency to the next meal of the crowded pigs was greater than that of the uncrowded pigs (187 vs. 142 ± 14 min; $P = 0.01$). Pigs in large groups ate fewer but longer meals, with longer mean latency to the next meal over the entire study and during individual observation periods, compared with pigs in small groups (Figure 3).

Group size × space allowance interactions existed for mean meal duration. Crowding reduced mean meal durations in larger groups but increased durations in small groups (8.25, 6.45, 4.81, and 5.71 ± 0.66 min for large uncrowded, large crowded, small uncrowded, and small crowded, respectively; $P = 0.01$). The same pattern was evident during the third observation period (BW = 65 kg; $k_C = 0.032$; $k_{UC} = 0.048$; 7.38, 5.72, 4.83, and 6.42 ± 0.87 min for large uncrowded, large crowded, small uncrowded, and small crowded, respectively; $P = 0.043$). Interactions of group size and space allowance also existed ($P < 0.05$) for overall total duration of eating. Again, large uncrowded had a greater total duration than all of the other treatment combinations, which did not differ from each other (67.0 vs. 56.5, 54.8, 53.9 ± 4.2 min/24 h for large uncrowded, large crowded, small uncrowded, and small crowded, respectively; $P = 0.03$).

Physiological Measurements

Salivary Cortisol Concentrations. With the exception of the first sampling week, there were no differences ($P > 0.05$) in salivary cortisol concentrations among treatment combinations. During that week, the average rank for the large uncrowded treatment was 1.25, compared with 2.00, 3.25, and 3.50 for small uncrowded, small crowded, and large crowded, respectively ($P < 0.05$). Within the first sampling period, individual samples were analyzed to determine whether there were differences in the cortisol concentrations between samples obtained in less or more than 5 min of the technician entering the pen. It was determined that the average cortisol concentration of the sample, when taken in under 5 min, was not different from the average cortisol concentration of the sample when taken in more than 5 min.

Adrenal Gland Analysis. Space allowance did not affect ($P > 0.05$) measurements taken from the adrenal glands. Group size effects were only evident on the gland weight:100 kg of BW ratio. Pigs housed in small groups had a smaller ratio than pigs housed in large groups (2.358 vs. 2.578 ± 0.064 g/100 kg of BW; $P = 0.028$). There were no interactions of group size and space allowance.

Sex

Within the first 2 blocks, differences between gilts and barrows were established. Overall, barrows gained more than gilts (1.064 vs. 1.012 ± 0.009 kg/d; $P = 0.018$). There were no differences ($P > 0.05$) in the injury scores of barrows and gilts.

DISCUSSION

Crowding pigs resulted in reduced overall productivity, with the greatest effect late in the study when pigs were most crowded. Space restriction ($k < 0.034$) has been associated with reduced gains (Brumm and Miller, 1996; Eisemann and Argenzio, 1999), reduced feed intake (Hanrahan, 1981), and reduced G:F (Brumm and Miller, 1996; Brumm and the NCR-89 Committee on Swine Management, 1996), although effects on G:F have been variable.

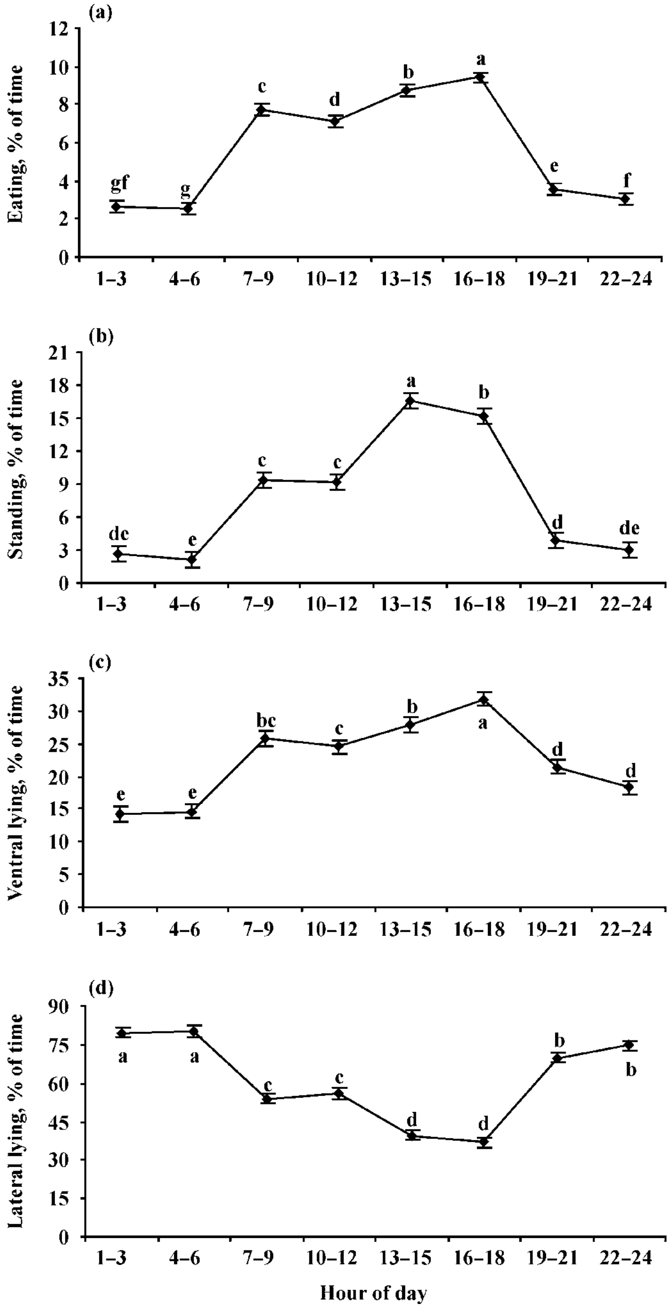

Figure 1. The overall proportion of time that grower-finisher pigs in blocks 3 through 8 spent (a) eating, (b) standing, (c) lying ventrally, or (d) lying laterally at different time periods throughout a 24-h day. [a–g]Means that do not have a common letter differ ($P < 0.05$). Error bars represent the mean ± SEM. *P*-values are derived from the analysis of the square root transformation of the raw data for (a) eating and (b) standing, whereas *P*-values for (c) ventral lying and (d) lateral lying are derived from analysis of the arcsine transformation of the raw data.

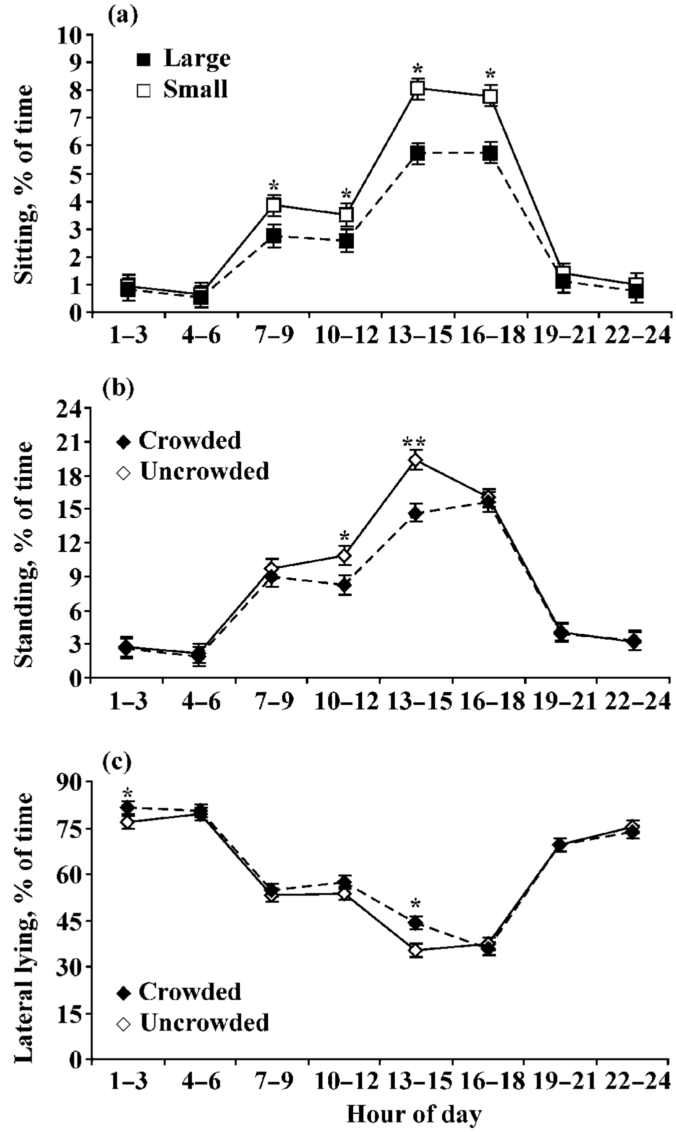

Figure 2. The proportion of time that grow-finish pigs in large (108 pigs; ■) or small (18 pigs; □) groups, or at crowded (0.52 m^2/pig; ◆) or uncrowded (0.78 m^2/pig; ◇) space allowances, spent (a) sitting, (b) standing, or (c) lying laterally within each observed time period in blocks 3 through 8. The figures represent an average of data taken from each block at 2-wk intervals. Error bars represent the mean ± SEM. Symbols indicate the comparison for differences between values (*$P < 0.05$; **$P < 0.001$); *P*-values are derived from the analysis of the square root transformation of the raw data for (a) sitting and (b) standing, whereas *P*-values for (c) lateral lying were derived from analysis of the arcsine transformation of the raw data.

Crowded pigs were also observed eating less frequently than uncrowded pigs. The degree of physical restriction imposed on pigs near the end of the study may have been responsible for hindering feeder access, because mobility was most restricted at that time. This hypothesis is supported by videotape data, which showed that crowded pigs ate fewer meals and had greater latency to their next meal than uncrowded pigs, but only during the final observation period when they were most crowded ($k_C = 0.025$).

We hypothesized that a shift from lateral lying to the less space-demanding ventral lying would occur in

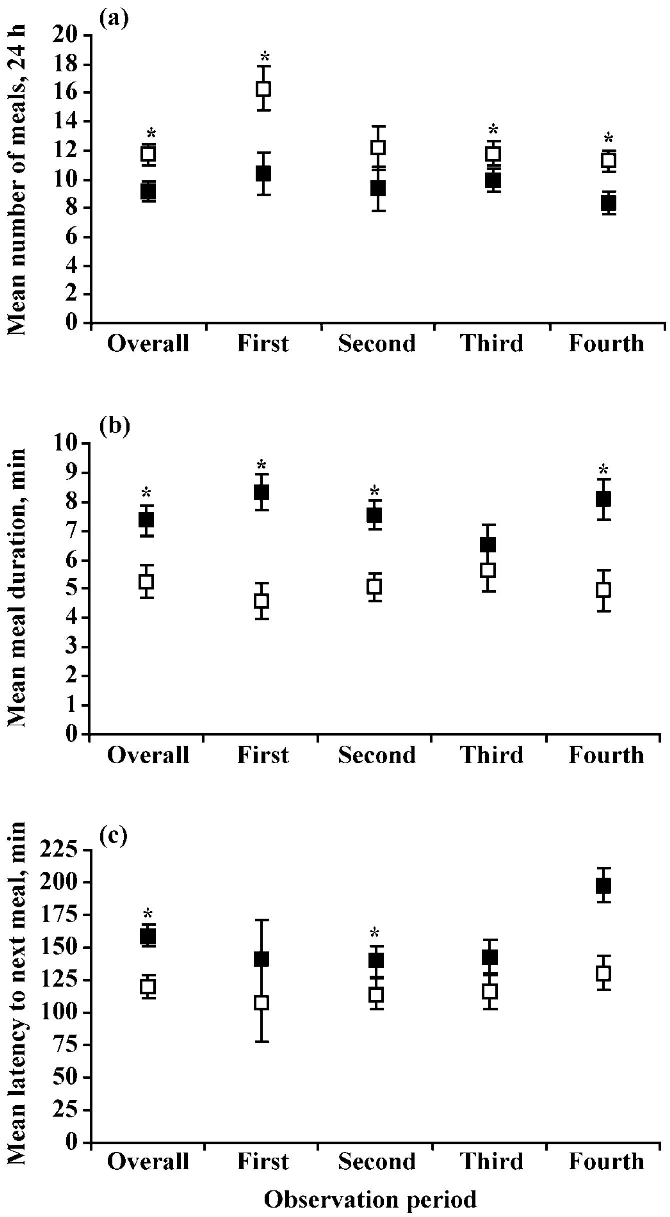

Figure 3. The mean number of meals, mean meal duration, and mean latency to the next meal of grow-finish pigs housed in large (108 pigs; ■) or small (18 pigs; □) groups in blocks 3 through 8. Data were taken from each block at 2-wk intervals. First = 43 kg of BW; second = 65 kg of BW; third = 80 kg of BW; fourth = 95 kg of BW. Error bars represent the mean ± SEM. Symbols indicate the comparison for differences between values (*$P < 0.05$); P-values are derived from the analysis of (a) the square root transformation of the raw data or (b, c) the base-10 logarithm transformation of the raw data.

crowded conditions. In contrast, the proportion of time pigs spent lying laterally did not differ among space treatments. The diurnal patterns of the 2 lying postures were dissimilar, with ventral lying following a pattern similar to that of active behaviors such as standing and eating, whereas lateral lying reflected an opposite pattern. This suggests that the 2 lying postures reflect different motivations and as such they would not be substituted for each other as a means of space conservation. When housed in large groups, pigs spent less time sitting and lying ventrally than pigs housed in small groups and more time lying laterally, which appears to be a more restful posture.

Literature has indicated that pigs are observed sitting or standing motionless more often when housed under restricted space allowances, behaviors thought to be a strategy for coping with the stress of crowding (Pearce and Paterson, 1993). The behavior of crowded pigs in the current study did not indicate that they were experiencing a greater level of stress than uncrowded pigs, because overall sitting and standing behaviors were unaffected by space restriction. The prevalence of tail biting, which has also been linked to intolerable levels of stress (Schroder-Petersen et al., 2004), did not differ between the 2 space-allowance treatments. Furthermore, results from the salivary cortisol and adrenal gland analyses, measures of acute and chronic stress, respectively, failed to demonstrate that crowded pigs experienced a greater level of stress than uncrowded pigs. Crowded pigs experienced more leg lesions than uncrowded pigs but only during the final scoring period when they were most crowded ($k_C = 0.025$).

In a study of similar length, Samarakone and Gonyou (2003) found that ADG was reduced by 2% in large groups (108 pigs) when compared with small groups (18 pigs). The current study indicated an overall difference of 3.5%. Reviews by Wolter and Ellis (2002) and Turner et al. (2003) suggest that a decrease in ADG of as much as 2 to 6% could be expected for an increase in group size from 18 to 108 pigs for grower animals. The 3.3% difference in initial BW indicates that additional production losses may have occurred as soon as the large groups were formed. During the first 2 wk alone, pigs housed in small groups were outperforming their large-group-housed counterparts by 5.4%, which further supports the theory of an early effect of group size. Samarakone and Gonyou (2003) found the difference to be 10% during the first 2 wk, whereas Schmolke et al. (2003) found the difference to be 12% (10 vs. 40 pigs). We suggest that ADG is reduced during the adaptation to living in a large group but that after this initial period, growth may be unaffected by group size. Thus, the negative effect of group size is seen in short studies or in the early (nursery or grower) stages of longer studies.

Overall, pigs in large groups ate fewer meals and had a greater latency to their next meal but took longer to eat a meal. Thus, the proportion of time spent eating in a 24-h period did not differ between the group sizes. Turner et al. (2002) reported a decrease in meals per day among lightweight pigs in large groups but not in heavy animals. The behavior seen among the pigs in our large groups resembles that of animals that experience difficulty obtaining a resource or that must travel some distance to obtain said resource. In our study, feeders in the large-group pens were assembled together at 1 end of the pen, as opposed to being spread out equidistantly. Therefore, pigs may have experienced difficulty traveling through the large group to reach the feeders. These data do not suggest that an increase in feeding behavior (Spoolder et al., 1999) or an increase in competition at the feeder (Wolter and Ellis, 2002), as predicted for pigs housed in large groups, was occurring.

Greater leg lesion scores were recorded among pigs housed in large groups, as were greater lameness scores. One explanation is that pigs housed in large groups spent more time lying laterally than pigs in small groups, which may have included more frequent posture changes, increasing the occurrence of skin abrasions and lameness. Another possibility relates to the fact that large groups have more space available for running. Pigs that are able to run around more frequently are more likely to get their feet caught in the slats while running. Causal observations have indicated that pigs running in the larger pens often ran into other pigs or walls. This, too, may have increased leg injuries.

Studies of an empirical nature (space expressed on an area/pig basis) often find that crowding reduces overall productivity, but they fail to determine the precise point at which crowding and growth depression begin (Harper and Kornegay, 1983; Meunier-Salaun et al., 1987; Brumm et al., 2001). Expression of space using the k coefficient derived from the allometric equation area = $k \times BW^{0.667}$ (Petherick and Baxter, 1981) allows use of a broken-line analysis to determine the critical point at which crowding and growth depression begin and the rate at which productivity is depressed as further reductions in space allowance occur. The effect of space restriction may be reduced in large groups of pigs compared with small groups due to the sharing of common space for movement. We found that the response of small and large groups to crowding did not differ. In fact, the numerical trend suggested that large groups reduced ADG at greater space allowances than did small groups. We found no support for the hypothesis of McGlone and Newby (1994) that large groups should respond less than small groups to space restriction.

Our assessment of the hypothalamic pituitary adrenal axis was limited to circulating levels of cortisol and adrenal morphology and did not include adrenal function tests. Previous studies on the effects of crowding on the hypothalamic pituitary adrenal axis under commercial conditions have also failed to detect differences (Kornegay et al., 1993), but effects were found when a wider range of space allowances were included (Meunier-Salaun et al., 1987). Crowding in commercial conditions represents a gradual onset, chronic stressor, and as such may be difficult to assess using the limited battery of hypothalamic pituitary adrenal axis tests we included in this study.

Large-group housing is not as detrimental to grow-finish pigs as once presumed (English et al., 1988). Effects on productivity are limited to the initial period of adaptation to the system. In contrast, effects of crowding are only evident at the end of the production period, and the 2 management factors appear to work independently of each other. There is little evidence that pigs in large groups are better able to adapt to space restriction than those in small.

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