THE EFFECTS OF HOUSING GROW-FINISH PIGS IN TWO DIFFERENT GROUP SIZES AND FLOOR SPACE ALLOCATIONS

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ABSTRACT

Crowding of grow-finish pigs reduces growth and is considered a welfare issue. Most crowding studies have been limited to smaller group sizes than are currently being considered in the swine industry. It has been hypothesized that pigs in large groups require less space to maintain growth and welfare. The objective of this study was to examine the effects of group size and space allowance on the performance, health and welfare of grow-finish pigs.

The study consisted of eight blocks, each with four experimental units in a 2 x 2 factorial arrangement of group size (18 vs. 108 pigs/pen) and space allowance (0.52 vs. 0.78 m^2/pig). Health assessments were conducted daily; production data were collected weekly; injury scores, behaviour and salivary cortisol data were collected bi-weekly; and carcass and adrenal gland data were collected at slaughter.

Gains were lower for crowded pigs, but the effects were limited to the final week of the study. Pigs in crowded groups had a lower feed efficiency, which followed a trend similar to that of gains over time. In the crowded groups, pigs spent less time at the feeder, but no other variables differed among space allowances.

Gains were lower for pigs housed in large groups, but the effects were limited to the initial two weeks of the study. Pigs in large groups had a lower feed efficiency and more lameness and leg sores. Other health measures did not differ between the group sizes. Lying behaviour of pigs in large groups indicated that they were able to utilize free space more efficiently than pigs housed in small groups.

Analysis of feeding patterns suggests that pigs housed in large crowded groups were able to manoeuvre around their environment more easily than those in small crowded groups, yet performance of pigs in large groups was similarly affected by space restriction as pigs in small groups. Interactions of group size and space allowance indicated that pigs in large crowded groups were more susceptible to lameness. There was no indication that pigs in large groups required less space, or could perform as well at reduced space allowances, than pigs in small groups.

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DEDICATION

I would like to dedicate this thesis to my mom, Allene Larrivee, and my dad, Ray Street. Although their own careers have led them down entirely different paths than the one I have chosen for myself, they have always taken a genuine interest in what I have been doing. Their love and support have helped me become the person I am today.

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LIST OF ABBREVIATIONS

ACTH	adrenocorticotropic hormone
ADFI	average daily feed intake
ADG	average daily gain
ANOVA	analysis of variance
avg	average
BW	body weight
C	crowded group
CV	coefficient of variation
d	days
df	degrees of freedom
etc.	etcetera
GENMOD	generalized linear model
G:F	gain-to-feed ratio (feed efficiency ratio)
GLM	general linear model
GS	group size
h	hour
k	a space coefficient value used in space allocation equations
kg	kilogram
L	large group
LC	large crowded treatment
LUC	large uncrowded treatment
m	meter
min	minute
MIXED	mixed model
mm	millimeter
NONLIN	non-linear model
OR	on-rail
P	probability value
PROC	procedure
R^2	multiple coefficient of determination
S	small group
SAS	statistical analysis system
SC	small crowded treatment
SD	standard deviation
SEM	standard error of the mean
Sp (SP)	space or space allowance
SUC	small uncrowded treatment
TP	time period
UC	uncrowded group
VCR	video-cassette recorder
wk	week
wt	weight
vs.	versus

1. LITERATURE REVIEW

1.1 Introduction

Traditionally, pigs have been housed in group sizes of less than 25 pigs per pen (Gehlbach et al., 1966; Hsia, 1984; Barnett et al., 1986). However, the hog industry is beginning to shift towards housing grow-finish pigs in groups as large as 100 to 1000 pigs per pen or more. Appropriate management practices have yet to be determined for this type of housing. Studies have indicated that daily gain is depressed by approximately 2 % for pigs housed in large groups compared with pigs housed in small groups (Wolter et al., 2001; Turner et al., 2000), but this growth depression usually only occurs within the first few days or weeks of the trial period (Samarakone and Gonyou, 2003b; Schmolke et al., 2003). It has been suggested that large group housing will benefit the hog industry through a more efficient use of free space, which is the space available to all pigs in the pen at any given point in time (McGlone and Newby, 1994). However, this has not been definitively shown, and it remains unclear whether pigs housed in large groups do, in fact, make more efficient use of space.

Past studies on space allowance have traditionally been empirical in nature, reporting the overall performance of pigs at different space allowances (Harper and Kornegay, 1983; Meunier-Salaun et al., 1987; Brumm et al., 2001). These studies often found that crowding does in fact reduce overall productivity, but they failed to determine the precise point at which crowding and growth depression began.

An alternative approach, when studying crowding, is to express space allowance based on an allometric equation relating body weight to floor area. The equation used is $k = \text{Area} \div \text{BW}^{0.667}$, where area is in m^2 and body weight (BW) is in kilograms (Petherick and Baxter, 1981). The use of this equation is more effective for expressing pig space needs because it reflects a consistent space requirement that applies over a range of body weights (Gonyou et al., In Press).

The allometric space allowance equation enables the use of a broken line analysis to determine the critical *k* value at which performance is negatively affected by the amount of space provided. To use such an analysis, a ratio must first be created relating a particular performance variable of the crowded treatment to that of the uncrowded treatment, evaluated over a specific time period (i.e. daily gain of the crowded treatment versus daily gain of the uncrowded treatment for each interval that gains were calculated). The daily gain of the uncrowded treatment will always be set at 100 % (or zero; see point 'A', Figure 1.1) while the daily gain of the crowded treatment will be expressed as a proportion of that value (see point 'B', Figure 1.1). Then, values are plotted against their corresponding *k* value for that interval. The intersection of the uncrowded and crowded trendlines will yield a break-point, which represents the critical *k* value and the point at which productivity begins to decline (see point 'C', Figure 1.1). Prior to reaching the critical *k* value, performance is essentially at a plateau. In other words, maximum productivity is being achieved (Gonyou et al, In Press).

According to Gonyou et al. (In Press), the critical value at which space allowance begins to negatively affect production is $k = 0.034$, and growth is depressed by approximately 0.5 % for every 1 % reduction in space beneath that value. So, at $k = 0.034$, pigs weighing 65 kg require 0.55 m^2 of space per pig whereas pigs weighing 95 kg require 0.71 m^2 of space per pig. Other findings are similar, indicating that the critical value occurs at $k = 0.032$ to $k = 0.033$ (Brumm and NCR-89 Committee on Management of Swine, 1996; Goihl, 1996; Gonyou, 2004). These values were calculated based on the final body weights and space allocations (m^2/pig) provided in the papers, with the exception of Gonyou (2004) who used actual *k* values.

The rate at which productivity declines can be determined in order to assess the impact of crowding on productivity as further reductions in space allowance occur. This is done by measuring the slope of the line below the break-point. The broken line analysis can be used to measure the effects of crowding on many parameters, including gain, feed intake, feeding behaviour and postural changes, and changes in stress level to name a few.

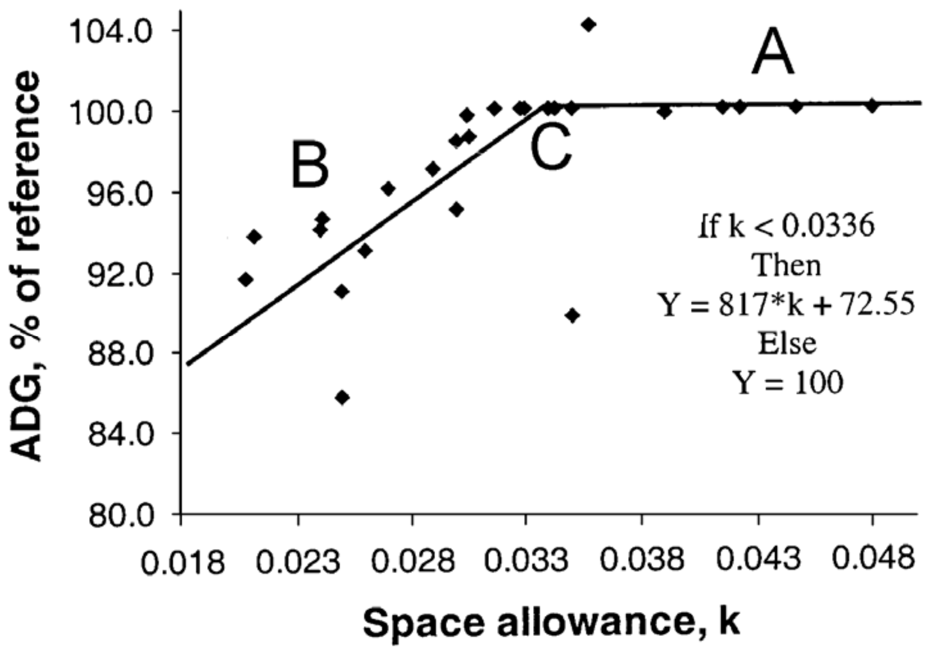

FIGURE 1.1 Example of a broken line analysis graph to determine the critical point of crowding and the rate of growth depression for grow-finish pigs (adapted from Gonyou et al. (In Press)). Point A illustrates the average daily gain of the uncrowded treatment; point B illustrates the average daily gain of the crowded treatment as a proportion of the uncrowded treatment; point C marks the critical point of crowding (the critical *k* value) at which crowding and growth depression begin.

Similar data based on large groups are not yet available. This study has been designed to determine the extent of crowding where production declines in both large and small groups using the allometric approach and the broken line analysis advocated. As well, this study will determine the effects of crowding of pigs housed in large and small groups on productivity, physiology, behavioural time budgets, carcass characteristics, and the health and welfare of grow-finish pigs.

Before getting into a discussion on findings in the literature, the issue of confounding must be addressed. Although the majority of the research to be discussed had the primary intention of focusing on the effects of group size or space allowance on pigs, in a number of cases the two factors have been confounded with each other, or with the effects of another factor, such as feeder space allowance. For example, crowding can be achieved by decreasing the size of pen, or by increasing the number of pigs in a given space. For a researcher with the intention of studying the effects of space restriction on pig performance, the former method would allow for valid interpretations, while the latter method would quite clearly be confounding space allowance with group size. Consequently, it can be difficult to determine whether differences in performance were a result of space allowance or group size. For the literature review, where possible, note of confounding factors was made so that the reader can make his or her own decision as to the validity of the researchers' findings and conclusions.

1.2 Space allowance

Space allowance has traditionally been expressed empirically by categorizing pigs into a series of weight ranges and by designating space on a per animal basis (Ewbank and Bryant, 1972; Bryant and Ewbank, 1974; Brumm and NCR-89 Committee on Management of Swine, 1996). Yet, such tables are mere conveniences and are hardly relevant to the pig's use of space. Empirical measures overlook body surface area as an important requirement for calculating space allowance. While studies using an empirical approach often find that crowding does reduce overall productivity, their weakness lies in their inability to determine precisely where crowding and growth reduction begins. Use of the allometric approach as described previously would be more effective because it reflects a consistent space requirement that applies to a range of body weights (Gonyou et al., In Press).

The allometric approach is most effective because it allows a broken line analysis to determine the critical point at which crowding begins, and it determines the rate at which productivity is depressed as further reductions in space allowance occur. Gonyou (2004) hypothesized that productivity would be maximized at levels of k above the critical value, and daily gain would decrease in a linear relationship with a decrease in k below the critical value. The only problem with using the allometric equation to establish floor area requirements is the difficulty in comparing results with traditional studies, since those studies have not employed similar methods of analyses (Gonyou and Stricklin, 1998). In this thesis, k values have been calculated based on the final body weights and space allowances provided in studies using traditional empirical methods of space allocation in order to compare the findings of those studies with more recent studies.

By altering space allowance, you can alter, suppress or displace an animal's normal behaviour patterns. Baxter (1986) conducted a study that provided pigs housed at thermoneutral temperature in a partially slatted pen with cold air blowing up through the slats. The idea was to provide an attractive (solid flooring) and unattractive (slatted floor, cold draught) lying area so that, when stocking density was increased, it could be observed when pigs began lying on the unattractive slatted area. When the change in lying area occurred, that indicated that the preferred space use exceeded the area available on the solid floor. Baxter (1986) reported that sows began lying on the draughty slatted floors as opposed to the solid flooring at a space allowance of $k = 0.025$.

From 25 kg and heavier, pigs prefer to lie together for most of the day (Ekkel et al., 2003). As they grow older, pigs begin to prefer fully recumbent lying postures (Ekkel et al., 2003). Therefore, floor space should facilitate this behaviour. In general, body space (static space occupied by the body), dynamic space (required to change posture or position in the pen), social space (accounts for the pig's group mate distance), and residual space (wasted space: ideally nil, but unavoidable) should be considered when total pen floor area requirements are being calculated (Baxter, 1985b; Curtis, 1999).

Many studies conducted to determine the most appropriate space allowance for the species in question conclude with recommendations. For example, Gonyou (2004) made recommendations of k = 0.033 and 0.034 for grow-finish pigs housed on full and partial slats, respectively. Edwards et al. (1988) recommended a space allowance of k = 0.030 because their findings indicated that, below that value, production and profitability began to decrease. In order to optimize weight gain, feed intake, gain:feed ratio, and rate of lean gain, Goihl (1996) recommended a space allowance range of k = 0.032 to 0.038. Brumm and NCR-89 Committee on Management of Swine (1996) were more generous in their space recommendations of k = 0.032 to 0.039 for optimizing production. From these values, area would total 0.84 to 1.0 m^2 per pig for pigs that reach 136 kg body weight.

Gonyou et al. (In Press) stated that crowding in grow-finish pigs housed on fully slatted flooring begins at k = 0.034. Using a broken line analysis, Gonyou et al. (In Press) reported that, for every 0.001 decrease in k (approximately 3 % of the critical k value), daily gain was decreased by 0.56 to 1.41 % and daily feed intake decreased by 0.36 to 1.05 %. Feed efficiency was unaffected. Recommendations for nursery pigs stated that they should be kept at no less than k = 0.032 (Gonyou, 2004).

In Canada, producers in the swine industry are encouraged to follow the space recommendations set out by Agriculture and Agri-Food Canada's 'Recommended Code of Practice for the Care and Handling of Farm Animals: Pigs' (AAFC, 1993). However, the space allowances are merely guidelines. Requirements may change somewhat with changes in environmental temperature, changes in ventilation, or changes in other factors within the environment. The following two tables (Table 1.1, Table 1.2) outline the recommendations set forth by the AAFC (1993) for growing pigs as well as for gilts and sows.

TABLE 1.1

Recommended pen floor space allowances for growing pigs

	Space allowance (m^2)		
Body Weight (kg)	Fully Slatted (k = 0.035)	Partial Slats (k = 0.039)	Solid Bedded (k = 0.045)
10	0.16	0.18	0.21
20	0.26	0.29	0.33
50	0.48	0.53	0.61
75	0.62	0.70	0.80
90	0.70	0.78	0.91
100	0.76	0.85	0.97
110	0.81	0.90	1.03

(AAFC, 1993)

TABLE 1.2

Recommended pen floor space allowances for replacement gilts and sows

	Space allowance (m^2)	
Body Weight (kg)	Partial Slats (k = 0.054)	Solid Bedded (k = 0.059)
100 - 150	1.5	1.7
150 - 200	1.8	2.0
200 - 250	2.1	2.3
> 250	2.3	2.6

(AAFC, 1993)

Within limits, more space yields better performance and improved welfare. When space is restricted, productivity may still be satisfactory from a commercial point of view. However, such space restrictions may be behaviourally and ethically unacceptable.

Imposing space restrictions on animals violates many of their ‘freedoms’ (Table 1.3). Firstly, by restricting space, the animal no longer has freedom from discomfort. It may be forced to lie in its own excreta, in cold or draughty areas, or in very close proximity to its penmates; an undesirable choice for a pig over 50 kg (Pearce and Paterson, 1993) or which may be heat stressed.

Secondly, an animal’s freedom to express normal behaviour is encroached upon when space is restricted. Space restricted animals are not able to play and be social as freely as they would normally be due to limited mobility. This may cause them to become stressed. Thus the animals may be more likely to exhibit stereotypic behaviours or vices as a result of trying to cope with the stress.

Thirdly, imposed space restriction does not ensure conditions that avoid mental suffering (Freedom # 5; Table 1.3). Suffering may occur when an animal fails to cope, or has difficulty in coping with stress either because the stress is too severe, complex or prolonged, or because the animal is unable to take the constructive action necessary to relieve the stress (Webster, 2001).

Lastly, an animal’s freedom from pain, injury and disease may be suppressed under restricted space allocations due to restriction of movement, which is linked to physical trauma and increased injuries due to fighting when group-housed (Baxter, 1985b). Furthermore, when a pig is forced to lie in its own excreta, as is the case in many space-restricted environments, the likelihood of disease contraction and spread are increased (Baxter, 1985b).

1.2.1 Types of space

Past work carried out by Ardrey and Lorenz (as cited by Freedman, 1975) states that animals want and need a certain amount of space. Animals that are not territorial in the wild, when put into controlled environments such as those provided in commercial

TABLE 1.3

The 'Five Freedoms and Provisions' to ensure animal welfare

1. *Freedom from thirst, hunger and malnutrition* -
   by ready access to fresh water and a diet to maintain full health and vigour.

2. *Freedom from discomfort* -
   by providing a suitable environment including shelter and a comfortable resting area.

3. *Freedom from pain, injury and disease* -
   by prevention or rapid diagnosis and treatment.

4. *Freedom to express normal behaviour* -
   by providing sufficient space, proper facilities and company of the animal's own kind.

5. *Freedom from fear and distress* -
   by ensuring conditions which avoid mental suffering.

(Webster, 2001)

operations, can become territorial or protective of their space, regarding it as their own (Freedman, 1975). If adequate space is provided, animals can live together peacefully because they are less likely to encroach upon each other's space. When their territory is encroached upon, an animal may feel threatened and instinctively attack the trespasser. As space becomes restricting, territoriality and aggression become stronger. Consequently, increased harm is caused to the animals resulting in shorter life spans, interference with the rearing of young, and increased offspring mortality (Freedman, 1975). Restricting space allowance has other effects on an animal's health and well being as well. Factors such as productivity, behaviour, stress levels, and physiology may also be affected, and will be discussed in more detail later.

Within a pig's environment, there are characteristically four types of space: feeding space, drinking space, resting space, and excretory space (Baxter, 1985b). The allocation of these spaces within the pen is important, and should be based on the performance of the different activities, keeping in mind that some of the activities may overlap.

It is also important that the pen is not designed in a way that pigs are unwilling to accept (Baxter, 1985b). Results of poor design may be that the pigs end up excreting on the solid floor of a partially slatted pen, defeating the purpose of the slats (Baxter, 1985b). They may then be forced to lie in their own excreta, as it is the solid portion of a pen that pigs prefer to lie on (Baxter, 1985b). Furthermore, poor pen design may result in a number of pigs excreting in the feeder (Baxter, 1985b).

1.2.1.1 Feeding and drinking space

A pig's main requirement during feeding is to be able to get to, and remain at the feed trough without feeling that their feeding space is threatened (Baxter, 1985a). Baxter (1992) stated that, as long as there is adequate space for all animals to get to the trough, there seems to be little advantage to providing extra space. In limit-fed systems, pigs should all be able to access the feeders at once. However, with commercial operations shifting towards housing pigs in group of 1,000 or more per pen, providing feeder space for that many animals at once is simply not feasible. Therefore, feeders are provided at a ratio that allows all pigs sufficient access to ad libitum feeders to maximize growth. It has been hypothesized that spreading feeders out may enable pigs to better access the feed, although it may also allow the pigs to choose one area of the pen for feeding and consequently underutilize feeders located elsewhere in the pen (Wolter and Ellis, 2002). However, Schmolke et al. (2003) disproved this hypothesis. Her findings indicated that 90 % of pigs housed in groups of 40 ate from every feeder and 80 % of pigs housed in groups of 80 ate from every feeder.

Recommendations state that waterers should be provided at a rate of one per every 20 to 25 pigs (Baxter, 1985b). Gonyou and Lou (2000) stated that 12 pigs could be fed from a single space feeder without negatively affecting productivity. Pigs that were provided with restricted feeding space spent less time feeding (Hsia et al., 1988). Reducing feeder space by 50 %, or from 270 mm to 135 mm for pigs housed in groups of 20 to 30 individuals per pen, reduced daily gain by 12.1 % and reduced gain:feed (Baxter, 1985b). Reducing feeder space may also increase the number of pigs fighting over access to the feeder (Baxter, 1985b).

1.2.1.2 Resting space

Pigs will choose a resting area based on the security of that area (Baxter, 1985b). A pig lying near a feeder or in the middle of a pen while other pigs are moving about is likely to be disturbed or stepped on frequently. Therefore, pigs will choose to lie in low activity areas, such as beside a wall or in a corner to prevent disturbances from occurring (Baxter, 1985a,b; Curtis, 1999).

Position and size of the resting area are strongly influenced by climatic factors (Baxter, 1985b). The pig is very sensitive to heat, cold, and air flow because of its thin hair coat (Baxter, 1985b). Therefore, it will also choose its lying area based on the temperature and ventilation in its environment (Baxter, 1985b).

Pigs thermoregulate behaviourally in two ways (Baxter, 1985b). They will adjust their lying posture in order to increase (lateral lying) or decrease (ventral lying) heat loss to the floor and modify their heat loss to the air (Baxter, 1985b; Baxter, 1986; Hicks et al., 1998; Ekkel et al., 2003). As they become warmer, pigs also tend to place as much distance between one another as possible (Baxter, 1985b). When they are cold, pigs will become more active, and when lying, pigs will huddle together with their legs tucked under them in a sternal (ventral) lying posture (Baxter, 1985b).

Pigs will not normally choose to lie in wet or draughty areas unless they are heat-stressed (Baxter, 1985b). In fact, a pig may instead designate hot or draughty areas as excretory places (Baxter, 1985b). Thus, it is very important to properly control temperature and ventilation so as to prevent pigs from excreting in inappropriate areas.

The amount of space required for a pig to lie laterally is greater than that required for a pig to lie on its sternum (Petherick, 1983; Ekkel et al., 2003). Imposing a space restriction can alter pigs' lying behaviour, forcing more of them to lie in a sternal recumbency position instead of the preferred lateral recumbency position, simply because crowding would physically restrict the number of pigs able to lie fully recumbent at once. The pigs may also be forced to lie in closer proximity to each other than they would normally choose, resulting in increased aggression and injury. Problematic behaviour and aggression due to space restriction are further compounded in overly warm environments.

1.2.1.3 Excretory space

In the wild, pigs have home ranges of 100 to 500 ha in which they have a communal nest and a discrete dunging area near the nest (Gonyou, 2001). In controlled environments, such as those found in commercial operations, there is a tendency for pigs to excrete feces, and occasionally urine, in a discrete place away from the feeding area and chosen resting place (Baxter, 1982; Baxter, 1985a,b; Curtis, 1999). Pigs will tend to lie away from their excretory space for thermal reasons, unless they are heat-stressed. When heat-stressed, the occurrence of dirty lying areas increases (Geers et al., 1989) and pigs use their excretory space as a wallowing site (Baxter, 1985b).

By restricting space, we take away a pigs' choice of how to use the space provided to them. Pens with adequate space allowances had obvious sleeping and dunging areas, while these were lacking in crowded pens (Heitman et al., 1961). Crowded pigs are no longer able to choose where to lie or where to excrete. As a result, they will eliminate feces and urine anywhere, and they will lie in the dunging areas. Such behaviour causes them to become wet and dirty and increases their likelihood of contracting a disease (Baxter, 1985b). Heitman et al. (1961) noted that crowded pigs were always more dirty, and they often defecated in water cups within a few hours of the water cup being cleaned.

1.2.2 Temperature and space

Pigs behave differently in hot or cold environments than they would at thermoneutral environmental temperatures (Hicks et al., 1998). Behavioural indicators are often the first signs of stress caused by an environmental temperature that is too high or too low (Hicks et al., 1998).

As they become warmer, pigs spend less time being active (Hyun et al., 2005), lie down more (Hicks et al., 1998; Hyun et al., 2005), and assume a lateral lying posture more often (Baxter, 1986). Thus, the space requirement of pigs increases when they are housed at temperatures above their thermoneutral zone (Baxter, 1985a,b; Baxter, 1986; English et al., 1988). Pigs which become heat stressed spend less time eating (Hicks et al., 1998; Hyun et al., 2005) and grow more slowly (Gehlbach et al., 1966; Harper and Kornegay, 1983). Therefore, space allowances should be increased during hot periods of the year (Gonyou et al., 1999).

Alternatively, when pigs become cold, they become more active and are found eating more often (Hicks et al., 1998) because they have higher maintenance energy requirements in cold environments (Petherick, 1983). They stand and sit more often than they lie down (Hicks et al., 1998), but when they are lying, their postural behaviour is more often sternal as opposed to lateral recumbency (Baxter, 1986). These findings suggest that pigs housed in cooler environments may require more social space but less static and dynamic space than pigs housed in warm environments.

Aggressive and problematic behaviours, such as tail biting, can increase when the animals are heat stressed (Baxter, 1985b), and the occurrence of diarrhea has also been shown to increase with increasing temperature (Geers et al., 1989). Kerr et al. (2005) found decreased gains and feed intake when ambient temperature was increased above the growing pigs' thermoneutral zone for an eight-week period. Alternatively, the findings of Hicks et al. (1998), who tested both heat and cold stressors placed on pigs for a four hour period, showed that neither daily gain, feed intake, nor feed efficiency was affected by the stressor before or after it was placed on the pigs. It is this author's opinion, however, that the limited amount of time the stressor was placed on the pigs in the study of Hicks et al. (1998) was inadequate to produce a change in the production parameters measured.

Table 1.4 outlines the thermal comfort zones of pigs varying in age. It shows the range in temperature at which pigs of various age or weight classifications should be kept. The recommendations have been put forth by the AAFC (1993).

1.2.3 Type of flooring as a determinant for space allowance

An extensive amount of research has focused on the best type of flooring on which to raise pigs, and whether provision of a bedded area is necessary (Gehlbach et al., 1966; Jensen et al., 1973; Kornegay and Notter, 1984; Gonyou et al., 1999; Sundhed, 2002; Hurnik et al., 2004). Many commercial operations today are opting for fully or partially slatted flooring simply because urine and feces are less likely to accumulate in the pen. Instead, the excrement falls through the slats into a manure pit, making fecal removal a much easier process. An accumulation of feces in the pen would cause the animals to become very dirty, and would provide an optimal environment for bacteria and other pathogens to reproduce (Baxter, 1985b). Full or partial slatted flooring may be more clean and sanitary, but it has been known to result in more leg problems (Gonyou et al., 1999; Sundhed, 2002). Sundhed (2002) found that pigs housed on solid flooring had a 1.8 times higher prevalence of lameness than pigs housed on deep litter. Pigs on partially slatted flooring had a 1.9 times higher prevalence of lameness than pigs housed on deep litter. Pigs on fully slatted floors had a 2.4 times higher prevalence of lameness than pigs housed in deep litter. When comparing full versus partial slatted flooring, Gehlbach et al. (1966) noted lower feed intake among pigs housed on partial slats, and reduced weight gains from 50 to 90 kg body weight as well.

TABLE 1.4

Thermal comfort zones for pigs at various stages of growth

Stage of Growth	Body Weight (kg)	Range of Zone (º C)
Piglet	Birth to 6 kg	24 - 34
Weaner	6 - 25	18 - 32
Grower	25 - 50	15 - 25
Finisher	50 - 100	15 - 25
Breeding Stock	> 100	10 - 21

(AAFC, 1993)

Kornegay and Notter (1984) conducted a review of the literature and hypothesized that floor space could be reduced for pigs housed on fully slatted floors compared with solid floors, without negatively impacting production. However, since their paper was a review of data collected from a number of facilities, it did not provide exact space allowances to allow comparisons with other studies. Jensen et al. (1973) found that daily gains of crowded (k = 0.020) pigs housed on fully or partially slatted floors were not significantly different.

English et al. (1988) stated that floor space requirements per pig are less on slatted and partially slatted floors than on solid floors. The space requirements for partially and fully slatted floor types recommended by Gehlbach et al. (1966) and Jensen et al. (1973) were the same (k = 0.028 from 18.0 to 45.5 kg; k = 0.032 from 45.5 to 68.0 kg; k = 0.034 from 68.0 to 95.5 kg). Work done by Gonyou et al. (In Press) found that the critical points of crowding on each floor type were, in fact, similar, but the effects of crowding beyond the critical point developed more quickly in pigs housed on partially slatted flooring.

Hurnik et al. (2004) compared a deep bedded system to a fully slatted system and found no significant differences in growth rate between pigs raised in either system, except during the summer time when bedded pigs grew slower. Similarly, there were no differences in feed conversion, disease incidence, or mortality, but pigs raised in the bedded system did have higher levels of backfat. Canadian recommendations for pig floor space allowances now differentiate between fully and partially slatted flooring so that producers can base the space they provide to their own pigs on the type of flooring available in their facility (AAFC, 1993).

1.3 Group size

Large group studies conducted before the year 2000 generally labelled groups of 8 to 25 pigs per pen as a ‘large’ group (Gehlbach et al., 1966; Hsia, 1984; Barnett et al., 1986). Recent large group studies have considered group sizes of 40 or more to be a large group (Wolter et al., 2000b; Samarakone and Gonyou, 2003b; Schmolke et al., 2003). The swine industry may be shifting towards the use of large groups, especially when automatic sort systems for the market pigs are used, simply to become more economically efficient. There are less labour and input costs associated with large group housing. In sow housing, forming large groups of sows due to farrow at a similar time would be a more economical use of space in gestation housing. It would also be easier to move one batch at a time than to move a few pigs from a number of pens.

The effects of housing pigs in groups of over 40 pigs per pen have not been widely studied, and therefore, research articles on this topic are few. However, recent hypotheses by scientists state that it may be possible to increase group size without negatively affecting production since pigs housed in large groups have a greater degree of control over their microenvironment (McGlone and Newby, 1994; Spoolder et al., 1999). Although the amount of space a pig physically occupies is the same in small and large groups, the increased control they have is derived, in part, from a larger amount of free space available for exercise and exploration when housed in large groups (McGlone and Newby, 1994; Spoolder et al., 1999). Providing large group housing may also be a better management strategy, allowing producers to minimize housing costs, maximize housing use, and therefore improve overall profitability (Wolter et al., 2000b).

Even though the optimal group size is affected by environmental factors, size of the animals, the facility in which the animals are contained, and method of feeding, such factors may, at first, be overlooked (Gehlbach et al., 1966; Baxter, 1985b). It is likely that decisions on the most appropriate group size to use in a particular situation will be made on the basis of production costs and ease of management (Wolter and Ellis, 2002).

Wolter et al. (2000a) found it was more profitable to use conventional group sizes of 20 compared with 100 pigs per pen in the nursery phase because of the significant growth depression that occurs during that time. The lower facility and equipment costs associated with larger groups only resulted in a marginal reduction in the total production costs per pig. However, Wolter et al. (2002) stated that large group size did not affect grow-finish pigs as negatively as nursery pigs, and therefore, the most economical group size for grow-finish pigs may be larger than for nursery pigs.

In the wild, pigs exist in small groups of adult females with neonate offspring (Gonyou, 2001). Males reside in separate groups outside of the breeding season (Gonyou, 2001). So it is normal to assume that pigs may be stressed when first mixed into large groups. However, stressors associated with large group sizes are thought to be short lived, primarily occurring right after mixing when levels of aggression are at their peak (Schmolke et al., 2003). It is at this time that the animals are attempting to establish some form of dominance hierarchy.

1.3.1 Dominance hierarchies within large groups

Dominance is an emergent property, not one that is inherited (Baxter, 1985b). Only characteristics of dominance, such as size, gender, colour, and personality can be inherited (Baxter, 1985b). Pigs recognize the characteristics of dominant individuals through visual, auditory, and olfactory cues (Baxter, 1985b).

Within most groups of two or more animals, there is some form of dominance hierarchy. A dominance hierarchy, or 'pecking order', is a system in which some animals in the group hold higher rank than others of the group. The system applies to all animals in the group, including newborns. Higher ranking animals have access to the best sleeping and lying areas, the first chance at food or kills, and are groomed by others in the group most often. The highest ranking individual is often the pack or group leader, making decisions for the group and maintaining social cohesion in the lower ranks (Baxter, 1985b). Maintenance of a dominance hierarchy requires an ability to discriminate between individual group members and periodic reinforcement of dominance relationships (Turner et al., 2001).

The dominance hierarchy is most commonly a linear one, although triangular forms have been found as well (Ewbank and Bryant, 1972). Linear hierarchies have a top ranking individual, and each other group member's rank falls beneath that individual, but remains in a linear pattern. For example, animal 'A' may be the highest ranking individual, followed by animal 'B', then 'C', and so on. Animal 'A' is dominant to all others in the group, while 'B' is dominant to everyone except 'A', and 'C' is dominant to everyone except 'A' and 'B', etc. A non-linear hierarchy means that animal ‘A’ may be dominant to ‘B’, ‘B’ to ‘C’, and ‘C’ to ‘D’, but animal ‘A’ is not necessarily dominant to animal ‘D’. The relationship may be triangular, where ‘A’ is dominant to ‘B’, “B’ to ‘C’, but ‘C’ is dominant to ‘A’ (Ewbank and Bryant, 1972; Baxter, 1985b).

For pigs, the hierarchy is most commonly a linear one, but it may undergo changes in the middle rankings (Baxter, 1985b). Arey (1999) noted that six out of nine groups of sows formed a linear hierarchy and the other three groups formed a non-linear hierarchy. Of the non-linear groups, one had a reversal of rank one week after re-grouping.

Feral pigs have a matriarchal dominance hierarchy that is retained as the predominant means of social organization in indoor conditions, despite the artificial grouping of animals on the basis of similarity in weight and age (Turner et al., 2003). The higher ranking individuals are able to eat whenever they want to, displacing lower-ranking pigs already in the feeder, even if there is extra feeder space available. Spicer and Aherne (1987) noted that, when all pigs tried to feed simultaneously, aggressive behaviour such as biting occurred even though the amount of feeder space per pig exceeded recommended levels.

English et al. (1988) stated that the maximum group size within which it is possible to have a stable social order was in the range of 30 pigs per pen. Above this number, it has been proposed that levels of aggression and restlessness would increase due to the increased probability of mistaken identity and reduced recognition (Baxter, 1985b; English et al., 1988). Baxter (1985b) stated that pigs housed in groups of over 100 individuals may have insufficient contact with each of their penmates to allow for learning of identity and relative status. However, neither Spoolder et al. (1999) nor Samarakone and Gonyou (2003a) found any differences in the level of aggression between large and small groups.

Other scientists believe that it is possible that pigs housed in large groups adopt a modified social strategy in order to minimize social stress. There have been a number of hypotheses on how pigs behave once formed into large groups. Andersen et al. (2004) hypothesized that aggression among unacquainted pigs is a function of group size. However, they state that as the number of potential competitors increases, more individuals will benefit by not getting involved in costly fights. Having dominance relationships with other individuals is only of benefit when the probability of meeting the same individuals repeatedly over time is high, and that is not always the case in large groups (Estevez et al., 2002). As group size increases, there comes a point where it is no longer possible for an individual to defend limited resources through aggressive acts since, when aggression is directed toward a particular individual, others are able to exploit resources (Estevez et al., 2002). Therefore, the probability of being able to monopolize resources diminishes as group size increases (Andersen et al., 2004).

Similarly, researchers have hypothesized that pigs (Turner et al., 2001) and chickens (Estevez et al., 2002; Estevez et al., 2003) may develop a greater social tolerance towards other group members as group size increases. In other words, animals will tolerate certain individuals rather than acting aggressively towards them because the potential cost of fighting (i.e. injury, energy expenditure, loss of body condition, etc.) in the large group is too high (Turner et al., 2001; Estevez et al., 2002). The findings of Samarakone and Gonyou (2003a) indicated that pigs housed in large groups appeared to adopt a non-aggressive, tolerant social strategy. The similar levels of aggression seen among group sizes of 20, 40 and 80 pigs per pen in the study carried out by Schmolke et al. (2004) also support the tolerance hypothesis. Studies conducted on large and small groups of chickens have supported the tolerance hypothesis as well (Estevez et al., 2002, 2003; D'Eath and Keeling, 2003).

D'Eath and Keeling (1998) suggested that pigs housed in large groups may be using status signals to spontaneously assess the competitive ability of their penmates before deciding whether to fight with a certain individual or not, rather than fighting with every penmate to establish a dominance hierarchy. In a review of the literature, D'Eath and Keeling (2003) indicated that hens might use a combination of displays, such as posture and structural features, to establish a hierarchy. Their findings indicated that aggressive hens housed in large groups were heavier and had larger combs than the hens they were aggressive towards.

A third possibility is that there is a spatial sub-division of the large group into smaller sub-units (sub groups) in which an efficient dominance hierarchy may be preserved between individuals housed in regular proximity (Oden et al., 2000; D'Eath and Keeling, 2003). Turner et al. (2003) also suggested that there is a possibility that pigs become familiar with only a limited number of group members, and casual observations carried out in the work of Curtis (1999) have indicated that animals in groups of 50 to 500 pigs do establish numerous smaller social subgroups of approximately 25 pigs each. Alternatively, Schmolke et al. (2003), who examined pigs' preference for certain feeders, Turner et al. (2003), who studied pigs' preference for certain resting areas, and D'Eath and Keeling (2003), who studied sub-grouping behaviour in laying hens, found that sub-grouping behaviour was not widely adopted among individuals in large groups. Turner et al. (2003) suggested that the limited space available for segregation, the need to share a common feeding area, and the phenotypic similarity of the animals may have inhibited the emergence of sub-groups. However, Turner et al. (2003) found location-based sub-grouping during resting.

Space allowance is an important factor in the establishment of social rank (Baxter, 1985a). When pigs are housed in space restricted environments, the dominance hierarchy becomes less stable (Jensen, 1982). Decreased stability most often resulted from the limited ability of a subordinate pig to retreat from a threat or act of aggression on behalf of the dominant pig. Therefore, the dominant pig does not recognize submission, and the fight may continue unnecessarily or resume later (Ewbank and Bryant, 1972; Bryant and Ewbank, 1972; Baxter, 1985a; Turner et al., 2003). Increased aggression may lead to increased injury levels and disease, and thus, increased stress. With an increase in stress, it is possible to reduce gains and lean growth potential, which in turn reduces appetite and average daily feed intake (Chapple, 1993). Furthermore, increased stress can increase the occurrence of stereotypic behaviours and vices, such as tail biting (Baxter, 1985b).

1.4 Productivity

1.4.1 Daily gain

Imposed space restrictions not only affect an animal's ability to experience the five freedoms (Table 1.4) but its performance may suffer as well. Space allowance studies on grow-finish pigs in small and conventionally sized groups (1 to 40 pigs per pen) are abundant. In general, the findings of these studies state that crowding significantly reduces average daily gain. The critical value at which crowding begins is $k = 0.034$ (Gonyou et al., In Press). Allotting space below a k value of 0.034 slowed growth in weanlings (Hugh and Reimer, 1967), growers (Jensen et al., 1973), and grow-finish pigs (Ford and Teague, 1978; Meunier-Salaun et al., 1987; Pearce and Paterson, 1993; Brumm and NCR-89 Committee on Management of Swine, 1996; Brumm and Miller, 1996). Gonyou et al. (1999) and Gonyou and Stricklin (1998) reported a growth depression of 5 % at $k = 0.030$. In a study carried out by Holck et al. (1998), uncrowded pigs ($k > 0.080$) grew faster and were able to reach market weight thirty-two days sooner than crowded ($k = 0.030$) pigs. In a grower study carried out by Hyun et al. (1998) using $k = 0.017$ for the crowded space allowance, a 16 % lower daily gain was observed for crowded pigs compared with uncrowded ($k = 0.038$) pigs. Similarly, Hale and Utley (1985) reported a 14 % decrease in gains for crowded pigs ($k = 0.019$).

Body weight variation within a pen is not as predictable as average daily gain when space restrictions are imposed. Ford and Teague (1978) reported that there was a greater variation in individual body weights when the mean weight of crowded pigs reached 99 kg. Alternatively, Brumm and the NCR-89 Committee on Management of Swine (1996), Brumm and Miller (1996), and Gonyou and Stricklin (1998) found no effects of crowding ($k = 0.024$, 0.024 and 0.030, respectively) on body weight variation.

A wean-to-finish study conducted by Wolter et al. (2000c) noted that diminished average daily gains started at week two when the crowded pigs were an average of 6.7 kg body weight. The final crowded k value of 0.030 was reached at approximately 45 kg. Gonyou (1999) pointed out that, for grow-finish pigs, the effects of crowding were evident in as little as four weeks. Changing from a crowded to uncrowded space allowance resulted in normal growth from then on, but there was no compensatory gain.

A review carried out by Kornegay and Notter (1984) concluded that, within the range of space allowances assessed in their review, for weanling pigs with an average final weight of 21.1 kg ± 0.6 (k = 0.024), every 0.1-m^2 increase in space above 0.18 m^2/pig increased daily gain by 8.6 %. For growing pigs with an average final weight of 53.5 kg ± 1.3, every 0.1-m^2 increase in space above 0.3 m^2/pig (k = 0.021) increased daily gains by 5.2 %. Similarly, for finishing pigs with an average final weight of 92.3 kg ± 1.4, every 0.1-m^2 increase in space above 0.7 m^2/pig (k = 0.034) increased daily gains by 2.6 %.

Results reported in studies using bovine and avian species were similar to those found using swine. Both Fisher et al. (1997b) and Fisher et al. (1997a) crowded heifers to k = 0.023. The results of their studies showed that average daily gain, and thus, final body weights were reduced due to crowding. Mogensen et al. (1997) found reduced gains for heifers housed at k = 0.031. Likewise, chickens also responded to reduced space allowances with slowed growth (Dawkins et al., 2004).

In a study on ovine species conducted by Horton et al. (1991), grower lambs were provided with space allowances of k = 0.073, k = 0.046, and k = 0.027. Their findings indicated that crowding to k = 0.046 was sufficient to reduce average daily gain by 14 %, but reductions beyond that value did not further reduce average daily gain. Baxter (1992) indicated that unshorn sheep required k = 0.055 for space, and the floor area requirement could be reduced by 15 % once the sheep had been shorn. The results of Horton et al. (1991) support this finding. The presence of straw bedding has also been suggested to increase the floor area requirement of sheep by 30 % (Baxter, 1992). A dirt floor was used in the study of Horton et al. (1991).

It is possible that reduced average daily gain at reduced space allowances may be due, at least in part, to a decrease in average daily feed intake (Kornegay and Notter, 1984; NCR-89 Committee on Confinement Management of Swine, 1993). Some studies are conflicting, but many agree that reduced space decreases average daily feed intake. The effects of space allowance on average daily feed intake will be discussed further later.

Among small, or conventionally-sized groups, gains of pigs were decreased with increasing group size. The daily gain of pigs housed in groups of three exceeded that of pigs housed in groups of 5, 6, 7, 10 or 15 and pigs housed in groups of 15 experienced decreased daily gain compared with pigs housed in the smaller groups (Gonyou and Stricklin, 1998). Hyun and Ellis (2001) found 6.4 % slower growth in pigs housed in groups of 12 compared with groups of two. Other researchers found no difference in growth rates among group sizes of 2, 4, 8, or 12 (Hyun and Ellis, 2002), or among groups of 15 versus 20 pigs per pen (Nielsen and Lawrence, 1993; Nielsen et al., 1995).

Although group size studies by Hyun and Ellis (2001) and Hyun and Ellis (2002) were confounded with feeder space allowance, they still provided their largest group (12 pigs) with what Gonyou and Lou (2000) deemed to be sufficient feeder space. Therefore, the group size information collected from their study was considered useful, since restricted feeder space was not an issue, and their finding were included into the following sections of this thesis as well. Nielsen and Lawrence (1993) and Nielsen et al. (1995) did not provide sufficient feeder space for their groups of 15 and 20 pigs per pen. Thus, it is more difficult to determine whether the results extrapolated from their study were the result of the reduction in feeder space allowance or group size.

A report based on a number of facilities indicated decreased average daily gain as the number of weaners per pen increased (Kornegay and Notter, 1984). In other research examining wean to finish systems, production appeared to have been most severely affected in the weanling phase. Gains were reduced by up to 6 % in groups of 100 compared with 20 or 25 pigs per pen in the period immediately post-weaning (Wolter et al., 2001; Wolter and Ellis, 2002). Pigs housed in groups of 100 had a 4 % lower daily gain than pigs in groups of 20 from 5.6 to 16.0 kg body weight (Wolter et al., 2000b). In a similar study, weaner pigs housed in groups of 100 had a 6.6 % lower daily gain than pigs housed in groups of 20 from 5.3 to 15.4 kg body weight, and had a 5.7 % lower daily gain from that point to 41.1 kg body weight (Wolter et al., 2000c).

Over the entire trial, the difference was 6.0 % (Wolter et al., 2000c). The negative effects of large groups on the performance of nursery pigs were not seen to the same extent in grow-finish pigs (Wolter and Ellis, 2002).

In grow-finish studies, daily gain was reduced for groups of 40 pigs compared with 10 or 80 pigs during the first two weeks of the trial, and daily gain was reduced in groups of 40 and 80 pigs compared with groups of 10 pigs during weeks 4 to 6 of the trial (Schmolke and Gonyou, 2000). Spoolder et al. (1999) also found effects of group size on pigs less than 65 kg. At that time, groups of 80 pigs had the lowest gains, followed by groups of 40 pigs. Groups of 20 pigs had the highest daily gain. Findings indicated a tendency ($P < 0.05$) for pigs housed in groups of 80 to have reduced gains during the first three weeks after group formation in a study carried out by Turner et al. (2002). Wolter et al. (2001) found effects of group size on gains of pigs during the finisher phase. Pigs housed in groups of 50 had a lower daily gain than those housed in groups of 100, and the gains of pigs in groups of 25 were intermediate (Wolter et al., 2001). Overall daily gain did not differ between the group sizes (Schmolke and Gonyou, 2000; Wolter et al., 2001; Turner et al., 2002).

Samarakone and Gonyou (2003b) did find an overall effect of group size on the gains of pigs housed in groups of 18 and 108. Pigs housed in the larger groups gained 2 % less than pigs in the small groups over the entire 11-week trial. However, reduced gains were most evident during the first few weeks (body weight < 45 kg), at which time the larger group pigs were gaining 10 % less than the smaller group pigs. Turner et al. (2002) suggested that the reduced gains seen in pigs housed in larger groups may have been due to a greater number of social interactions and exploratory behaviour following the formation of the group, which would have led to an increased energy utilization and resulting reduction in gain.

McGlone and Newby (1994) found no differences in daily gain between group sizes of 10, 20, or 40 pigs. Giles et al. (2001) found no negative association between group size and weight gain for group sizes of 20, 40, or 100 weaner piglets per pen.

Although the effects of group size on daily gain have not always been significant over the full extent of the trials, it is important to note that there were significant differences in the first few weeks after mixing (Spoolder et al., 1999; Schmolke and

Gonyou, 2000; Turner et al., 2002; Samarakone and Gonyou, 2003b). The depression in daily gain seen during those weeks was sufficient to cause a greater variation in body weight at the end of the trials, and as a result, was likely to affect profitability by delaying marketing of some pigs. It appears that large group sizes may have a disadvantage over small groups due to greater setbacks occurring at mixing of the large group.

1.4.2 Feed intake

A reduction in daily feed intake is often the first sign that pigs are experiencing stress due to crowding (Gehlbach et al., 1966; Hanrahan, 1981), and limited access to the feeding area may be the primary reason for reduced feed intake among space restricted pigs (Gonyou et al., 1999). Expressed numerically, Kornegay and Notter (1984) determined that, within the range of space allowances assessed in their review, for every 0.1-m^2 increase in space above 0.18 m^2/pig in the nursery (final weight = 21.1 kg ± 0.6), daily feed intake was increased by 7 %. Again, *k* values reported were calculated from final body weights and space allowances (m^2/pig) provided by the study's authors, and will be calculated in this way for any studies mentioned that do not report space allowances using *k* values.

Crowding below k = 0.031 has been shown to decrease daily feed intake of growers (Jensen et al., 1973; Bryant and Ewbank, 1974), finishers (NCR-89 Committee on Confinement Management of Swine, 1993; Holck et al., 1998), and of pigs studied throughout the grow-finish period (Gonyou et al., 1999). Hyun et al. (1998) saw these effects only at week four in a grower pig study. This week represented the end of their test period, at which time the pigs were most crowded (k = 0.017). Bryant and Ewbank (1974) reported that the effects of restricted space allowance were most evident in the latter part of the study when the pigs were most crowded, as well as overall.

Gonyou and Stricklin (1998) reported that reducing floor space to k = 0.030 resulted in a 4 % decrease in daily feed intake. Crowded (k = 0.022) grower pigs which reached a final body weight of 45.5 kg decreased their feed consumption by 10 % compared with their uncrowded counterparts in a study carried out by Hale and Utley

(1985). Further crowding of those pigs from 68.2 kg to 100 kg body weight (k = 0.019) decreased feed consumption by 28 %. Over the entire grow-finish study, crowded pigs consumed 20 % less feed than uncrowded pigs (Hale and Utley, 1985). However, it should be noted that the uncrowded pigs in the trial experienced values of k = 0.022, 0.025, and 0.030. Past studies concur that such values still represent a significant space restriction. Possibly, if the uncrowded pigs had been housed at values exceeding k = 0.035, the difference in daily feed intake would have been even greater.

After reviewing the available literature, Kornegay and Notter (1984) summarized that, within the range of space allowances assessed in their review, for growing pigs (final body weight = 53.5 kg ± 1.3), every 0.1-m^2 increase in space above 0.3 m^2/pig increased daily feed intake by 3.2 %. Similarly, for finisher pigs (final body weight = 92.3 kg ± 1.4), every 0.1-m^2 increase in space above 0.7 m^2/pig increased daily feed intake by 2.3 %.

A study on grower lambs determined that decreasing space from k = 0.073 to k = 0.046 was associated with an 11 % reduction in feed intake (Horton et al., 1991). Further reductions in space (k = 0.027) did not affect the lambs' feed intake. Again, this data suggests that lambs respond similarly to pigs when space allowances are reduced, but space requirements for lambs may be higher than that of pigs.

Studies carried out using grower pigs (Edwards et al., 1988), finisher pigs (Brumm and NCR-89 Committee on Management of Swine, 1996), and pigs studied throughout both the grower and finisher phases (Hugh and Reimer, 1967; Ford and Teague, 1978; Brumm and Miller, 1996; Brumm and NCR-89 Committee on Management of Swine, 1996) have found that crowding pigs below k = 0.035 did not affect daily feed intake. The studies were carried out at different times of the year using a variety of pig breeds, floor types, and sex ratios. One explanation for the conflict between these data and the majority of other research papers reviewed may be that the methods of data collection used in these studies were less precise, or perhaps feed intake is not actually affected by a reduction in space allowance.

Pigs housed in groups of three consumed more feed than pigs housed in groups of 5, 6, 7, 10, or 15 (Gonyou and Stricklin, 1998). Similarly, increasing the number of pigs per pen from 2 or 6 to 12 depressed feed intake (Harper and Kornegay, 1983; Hyun and Ellis, 2001), although the studies confounded group size with other factors, making it difficult to determine if the effects seen were true group size effects, or whether they were an artifact of feeder space allowance (Hyun and Ellis, 2001) or floor space allowance (Harper and Kornegay, 1983).

Daily feed intake was 5 % lower for weaner pigs housed in groups of 100 compared with those housed in groups of 20 for both halves of a weaner trial (Wolter et al., 2000b). Wolter et al. (2000c) found similar results among weanlings housed in the same group sizes, but only for the first half of the trial. A summary of data from a number of studies conducted by Kornegay and Notter (1984) indicated that daily feed intake decreased as the number of weanling pigs per pen increased, but significant effects were not seen in groups of grower or finisher pigs. Lower daily feed intake was suggested to be the reason for reduced daily gain in such studies (Wolter et al., 2000b). However, the problem lies in determining whether daily feed intake is responsible for controlling daily gain, or whether the relationship is actually the other way around.

Some studies using smaller group sizes have not found that group size affects feed intake (Hyun and Ellis, 2002). For large groups, some findings were similar. Pigs housed in groups of 20, 40, and 100 (Giles et al., 2001), in groups of 20, 25 and 100 (Wolter et al., 2001; Wolter and Ellis, 2002), in groups of 18 or 108 (Samarakone and Gonyou, 2003b), or in all, or a combination of, group sizes of 10, 20, 40, or 80 pigs did not yield different daily feed intakes (McGlone and Newby, 1994; Spoolder et al., 1999; Wolter et al., 2001; Turner et al., 2002; Schmolke et al., 2003). These findings suggest that a reduced daily feed intake may not be the primary reason for reduced daily gain seen in large groups of pigs, since it did not seem to be affected as often or as significantly.

1.4.3 Feed efficiency

Feed efficiency (G:F) is calculated from average daily gain (ADG) and average daily feed intake (ADFI). More specifically, G:F = ADG/ADFI. A change in feed efficiency occurs when either daily gain or daily feed intake changes significantly, but the other does not change. Similarly, a change in feed efficiency can be produced if both variables change significantly in opposing directions (i.e. one increases while the other decreases). However, if both variables are altered to the same extent and in the same direction (i.e. both increase or both decrease), then changes in feed efficiency may be difficult to observe. Therefore, it is important to consider gains and intake in combination with feed efficiency when interpreting the effects of any parameter on a pig's performance.

It seems most logical to assume that feed efficiency would either decrease in response to a stressful situation, or remain unchanged due to similar changes in daily gain and daily feed intake. Studies crowding wean-to-finish (Wolter et al., 2000c), grower (Edwards et al., 1988; Hyun et al., 1998), and grow-finish pigs to a level of k = 0.031 or less found poorer feed efficiency in those groups (Ford and Teague, 1978; NCR-89 Committee on Confinement Management of Swine, 1993; Brumm and NCR-89 Committee on Management of Swine, 1996; Brumm and Miller, 1996; Goihl, 1996). Horton et al. (1991) reported that feed efficiency was decreased by 17 % when space was reduced from k = 0.046 to 0.027 for grower lambs.

Conclusions put forth by Kornegay and Notter (1984) stated that, within the range of space allowances assessed in their review, for weanling pigs (final body weight = 21.1 kg ± 0.6), every 0.1-m^2 increase in space above 0.18 m^2/pig decreased feed efficiency by 1.2 %. For growing pigs (final body weight = 53.5 kg ± 1.3), every 0.1-m^2 increase in space above 0.3 m^2/pig decreased feed efficiency by 1.6 %. For finishing pigs (final body weight = 92.3 kg ± 1.4), every 0.1-m^2 increase in space above 0.7 m^2/pig decreased feed efficiency by 0.4 %.

Some studies have not found an effect of space allowance on feed efficiency (Hugh and Reimer, 1967; Jensen et al., 1973; Bryant and Ewbank, 1974; Pearce and Paterson, 1993; Brumm and NCR-89 Committee on Management of Swine, 1996; Gonyou and Stricklin, 1998), while others found an improvement in feed efficiency among crowded pigs (Meunier-Salaun et al., 1987; Holck et al., 1998). Meunier-Salaun et al. (1987) reported that feed efficiency increased by 7 % in the grower period and by 14 % in the finisher period for pigs crowded to k = 0.024 (final body weight of 100 kg). The results of Holck et al. (1998) showed a numerical improvement in feed efficiency with decreased space allowance, but it is important to note that the authors did not statistically analyze their data. Therefore, it is unknown whether the improvement was statistically significant or simply a trend.

Group size has also been proven to affect feed efficiency in some cases. In a study carried out by Wolter et al. (2001), their findings indicated that pigs housed in groups of 50 and 100 experienced poorer feed efficiencies than pigs in groups of 25 at the end of week eight on test. From week eight until the end of the trial (116 kg body weight), feed efficiency was better in groups of 100 pigs compared with groups of 25 and 50 pigs, but overall, feed efficiency was not affected by group size (Wolter et al., 2001).

The general consensus among large group studies was that group size does not affect feed efficiency. Feed efficiency was not significantly altered by large groups in studies using group sizes of 10, 20, 40, or 80 grow-finish pigs (McGlone and Newby, 1994; Spoolder et al., 1999; Schmolke et al., 2003), or group sizes of 20 and 100 pigs per pen in a wean to finish production system (Wolter et al., 2000b).

1.5 Behavioural time budgets

1.5.1 Feeding behaviour

Feed intake (kg/day) and feeding rate (g/min) have both been found to increase with increasing body weight (Hyun and Ellis, 2001), while feeding duration has been found to decrease with increasing body weight (Hsia et al., 1988). In summary, older, bigger pigs eat more but take less time to do it (Hsia et al., 1988; Gonyou and Lou, 2000).

The feeding pattern of pigs has been shown to follow a crepuscular pattern, which is a pattern composed of two peaks of activity (Feddes et al., 1989; Morrow and Walker, 1994a; Hyun and Ellis, 2002). In a study examining uncrowded pigs housed individually or in groups of eight, the most time spent eating was between 0500 and

0800 hours as well as 1100 to 1500 hours, creating two peaks in the pattern of daily food intake (de Haer and Merks, 1992). The larger peak in feeding behaviour occurred midday, from 1100 to 1500.

Crowded pigs (k = 0.017) made 29 % fewer feeder visits but spent 40 % more time at the feeder per visit and consumed 45 % more feed per visit than uncrowded pigs (Hyun et al., 1998). Ewbank and Bryant (1972), Bryant and Ewbank (1974), and Meunier-Salaun et al. (1987) also found that crowded pigs (k = 0.031, k = 0.024, k = 0.027, respectively) spent more time feeding. However, in the studies conducted by Bryant and Ewbank (1974) and Meunier-Salaun et al. (1987), the increased time spent feeding was not matched by an increase in daily feed intake. Instead, daily feed intake was lower for the crowded pigs in the study carried out by Bryant and Ewbank (1974). These results suggest that feeder occupation is not necessarily linked to ingestion of feed. The pigs may have been using the feeder as extra resting space instead. Hyun et al. (1998) stated that the response they found might have occurred because it was easier for the crowded pigs, using one of the two feeder types, to stay in the feeder. The protective crate in front of the feeder hopper extended the full length of the animal, making displacement by other pigs more difficult.

When examining the effects of restricted space allowance on feeding time in heifers, Fisher et al. (1997b) found that crowded heifers (k = 0.023) spent less time eating part way through the trial than uncrowded heifers, but there were no significant differences in feeding times between the crowded and uncrowded treatments over the entire duration of the trial. Similarly, Fisher et al. (1997a) found no effects of space allowance (k = 0.023, 0.029, and k > 0.035) on the amount of time heifers spent eating. These data suggest that space allowance has a different effect on ruminant animals than on monogastric animals, possibly due to the difference in digestive systems or feeding patterns.

As group size increases, it is thought that feeding behaviour is encouraged by the observation of others feeding (Spoolder et al., 1999). In theory, even when feeder spaces are provided at the same rate (i.e. the same number of feeder spaces per pig) in small and large groups, social facilitation may result in many pigs wanting to eat at the same time (Spoolder et al., 1999; Wolter et al., 2000b). Thus, the pigs may end up competing for feeder space, especially if certain feeders are preferred over others (Spoolder et al., 1999; Wolter et al., 2000b).

It was also hypothesized that placing feeders in a single central location may increase competition for access to the feeder (Wolter and Ellis, 2002), and dominant pigs would be more likely to restrict a lower ranking pig's access to those feeders (Spoolder et al., 1999). However, Morrow and Walker (1994b) did not find any differences in feed intake or growth rate between groups of 20 pigs kept in pens with single-spaced feeders side by side or separated. In a similar study using 100 pigs per pen, Wolter et al. (2000b) indicated that spacing feeders apart did not alter feed intake or growth rate compared with pens using feeders placed side by side.

A study testing feeding behaviour among varying group sizes found that pigs housed in groups of 20 ate significantly faster than those housed in groups of 5, 10, or 15 and consequently had shorter feeder occupation times (Nielsen et al., 1995). However, group size was confounded with feeder space allowance in their study, suggesting that the findings may be an artifact of reduced feeder space rather than group size.

In a non-confounded study, Turner et al. (2002) reported that pigs housed in groups of 80 occupied the feeder for less time per day than pigs housed in groups of 20. Nielsen et al. (1995) suggested that pigs were able to adapt to increased group size and decreased feeder space by eating less frequently, but eating more feed per visit. However, that did not necessarily mean that productivity could be maintained.

When groups of more than 40 pigs per pen were compared, there were no effects of group size (20 pigs/pen versus 80 pigs/pen) on mean feeding bout duration or the mean number of bouts in a 24 hour period (Turner et al., 2002). Spoolder et al. (1999) also found no effects of group size (20, 40, and 80 pigs/pen) on feeding behaviour.

It is important to note that, although results on feeder occupancy, feeding duration per pig per visit, and number of feeding bouts per day vary, findings are generally in contrast to the hypotheses put forward by Spoolder et al. (1999) and Wolter et al. (2000b) mentioned previously. Increasing group size does not appear to increase competition at the feeder due to social facilitation, and it seems to have only limited effects on feed intake.

1.5.2 Postural behaviour

The amount of space used by a pig varies depending on the posture they are assuming at that time. Using equations based on the pig body dimensions of height, breadth, and length, the space occupied by a pig resting on its sternum (ventrally) and resting fully recumbent (laterally) can be estimated (Petherick, 1983). For ventral lying, the amount of space required is equal to $0.019*BW^{0.66}$ whereas lateral lying requires an amount of space equal to $0.047*BW^{0.66}$, when body weight is in kilograms Thus, for a pig weighing 40 kg, 0.22 m^2 of space is needed to lie ventrally, while 0.54 m^2 of space is needed to lie laterally. To compare, a 95 kg pig would require 0.38 m^2 of space to lie ventrally and 0.95 m^2 of space to lie laterally. It should be noted that the value placed on lateral lying is likely high as it assumes no sharing of the space around a pig's body. Ekkel et al. (2003) estimated that the amount of free space around a pig's body that can be shared is 40 % (black portion of rectangle; Figure 1.2). In a crowded environment, it is likely that one would see a shift from the preferred lateral lying posture to ventral lying or another posture, simply because space restriction would allow fewer pigs to lie laterally.

Behavioural changes are often the first sign of stress due to crowding (Meunier-Salaun et al., 1987). Resting was the main activity observed among uncrowded pigs, occurring at a frequency of over 60 % of the behavioural time budget (Meunier-Salaun et al., 1987). When space was restricted below k = 0.024, pigs and heifers were observed lying and sleeping less frequently (Bryant and Ewbank, 1974; Mogensen et al., 1997; Fisher et al., 1997a,b). Reasons for this may be that the high stocking rate sufficiently reduced the lying area so that the animals could not sleep comfortably simultaneously.

Crowded (k = 0.025) grow-finish pigs were observed sitting or standing motionless more often than their uncrowded counterparts (Pearce and Paterson, 1993). Heifers were also observed standing more often when housed under restricted (k = 0.023) space allowances (Fisher et al., 1997a). Motionless sitting or standing behaviour has been suggested to be a 'cut-off' strategy that allows the animal to cope with an

FIGURE 1.2 Diagram showing the amount of space around a pig lying fully recumbent that is available for sharing with penmates. The black area of the rectangle represents the space available for sharing. (adapted from Ekkel et al. (2003))

unsuitable environment (Pearce and Paterson, 1993). Such behaviours are thus indicative of reduced welfare. Increased time spent standing may cause an increase in energetic costs, leading to a decrease in feed efficiency (Fisher et al., 1997a).

A study carried out on finishing heifers found that, under restricted space allowances, the animals spent less time in social activities and more time 'head-resting' (Fisher et al., 1997b). Head-resting behaviour occurs when a standing animal rests its head on a lying conspecific. It is presumed to occur most frequently when space allowances are restricted, but has been hypothesized to be performed by an animal that wishes to lie down where an animal higher in the social order is already lying (Wierenga (1983) according to Fisher et al., 1997b). Heifers in the Fisher et al. (1997b) study were observed head resting on inanimate structures as well as other animals, suggesting that this behavioural pattern may be a resting substitute for lying down.

When space allowance was not restricted, pigs preferred to spend most of their time lying in a fully recumbent, or lateral, postural position (Ekkel et al., 2003). This behaviour increases as pigs grow, and is especially evident at night (Ekkel et al., 2003). Imposing a space restriction may physically prevent pigs from lying in a fully recumbent position. At space allowances of $k = 0.027$ (Meunier-Salaun et al., 1987) and $k = 0.025$ (Pearce and Paterson, 1993), pigs were observed lying in a sternal recumbency posture more often than a lateral one.

Preference for certain lying areas became less obvious at restricted space allowances as well. Pregnant gilts, under crowded conditions, were observed lying in the dunging channel more often (Barnett et al., 1992); a behaviour seen most frequently when limited space does not allow for a choice of lying area. Removing the ability of a pig to choose its lying area may force it to lie in soiled areas, thus increasing disease transmission, injury due to slippage, morbidity, and mortality.

Group size has had varying effects on behavioural time budgets when the group sizes have been kept small. Hyun and Ellis (2002) found no effect of group size on the percentage of time spent sitting or standing, while Hyun and Ellis (2001) found that the time spent standing increased with increasing group sizes. In both studies, group sizes were 2, 4, 8, and 12 pigs per pen. Alternatively, Barnett et al. (1986) found that gilts housed in pairs were the most active ones. They spent more time standing than gilts housed in groups of eight. Time spent lying was increased with eight pigs per pen compared with other group sizes (Barnett et al., 1986), but was not significantly different between group sizes in the study carried out by Hyun and Ellis (2001).

In large group studies (10, 20, 40, and 80 pigs/pen), there were no effects of group size on manipulative, standing, or resting behaviours (Spoolder et al., 1999), or on sitting or lying behaviours (Schmolke et al., 2004). However, Schmolke et al. (2004) did find that the percentage of time spent eating was greater in pigs housed in groups of 40 compared with groups of 10 and 20. Groups of 80 did not differ from the other group sizes (Schmolke et al., 2004).

1.6 Injury levels

1.6.1 Skin lesions

By crowding pigs, it is possible to increase levels of aggression, as discussed previously. As a result, animals may experience an increased level of injury (Baxter, 1985b), such as increased lesion scores (Burnham et al., 1995). In a study carried out by Turner et al. (2000), a larger space allowance was associated with a lower lesion score. However, their pigs were housed on deep straw litter and were not crowded to a great extent. Therefore, the lesions found on the test pigs may not be representative of the lesions that would be found on pigs that had been more crowded and housed on full or partially slatted flooring.

In a study carried out by Turner et al. (2002), feeder space was restricted for pigs housed in groups of 20 and 80 using concrete to fill the excess space in the feeder. Although it was hypothesized that restricted feeder space would cause increased aggression at the feeder, skin lesion scores were not significantly affected (Turner et al., 2002).

It has been suggested that aggression is also increased in large groups, resulting in a higher degree of injuries (Randolph et al., 1981). However, the number of skin lesions was not significantly different between groups of 20 or 80 pigs per pen according to the findings of Turner et al. (2002), or between group sizes of 10, 20, 40 or 80 pigs per pen according to Schmolke and Gonyou (2000). Alternatively, Spoolder et al. (1999) found that grow-finish pigs housed in groups of 80 had a higher number of skin lesions throughout the trial than pigs housed in groups of 40 or 20, and pigs housed in groups of 40 scored higher than those housed in groups of 20. Skin lesions were highest in the first week, were reduced during the middle weeks, and peaked at the final skin lesion scoring session before slaughter at 85 kg.

1.6.2 Lameness

Locomotory disorders with the main clinical symptoms of lameness or paralysis are numerous for many reasons. Firstly, one or more of bones, joints, tendons, tendon sheaths, ligaments, nerves, muscles, claws, and other parts of the locomotory apparatus can be involved (Waldmann, 2004). Secondly, the causes of locomotory disorders are very diverse. They can be caused by trauma, infectious agents, malnutrition, metabolic disorders, or degenerative, hereditary, or congenital conditions (Waldmann, 2004). Finally, locomotory disorders have different focuses in suckling piglets, weaners, fattening pigs, and juvenile or adult breeding pigs (Waldmann, 2004). The characteristic behavioural symptoms of lameness include prolonged bouts of sitting behaviour, inability to rise, and weakness in the limbs when standing (van Nes et al., 2004).

Sundhed (2002) conducted a survey of many housing units and discovered that lameness occurred in 93 % of the units, although it was randomly distributed throughout the pens. At the level of the individual pig, lameness was found in 1.8 % of the pigs, and was the third most frequent disease symptom after ear necrosis (4.3 %) and respiratory tract disorders (2.1 %). Forty-nine percent more lameness occurred in pigs weighing 100 kg or more compared with those weighing 30 kg. Sundhed (2002) also found a link between type of flooring and prevalence of lameness. Pigs housed on solid floors had a 1.8 times higher prevalence of lameness than pigs housed on deep litter. Pigs housed on partially slatted flooring had a 1.9 times higher prevalence and pigs housed on fully slatted floors had a 2.4 times higher prevalence than pigs housed on deep litter.

Partanen et al. (2004) linked occurrence of lameness to birth weight, stating that the odds of lameness decreased by 3.6 % with every 0.1-kg increase in birth weight. Furthermore, the odds of lameness increased by 6.9 % with every 1 % increase in carcass leanness, and ad libitum feeding increased the risk of lameness compared with semi ad lib feeding or restricted feeding (Partanen et al., 2004).

Lameness in pigs over 30 kg was positively correlated with tail biting all year round according to the findings of Schroder-Petersen et al. (2004). This may have been because of the infection existing in the tail after the tail had been chewed. Infection will gradually climb from the chewed tail stump up the spinal cord, causing nerve damage and paralysis (Schroder-Petersen et al., 2004).

Restricted space environments have been linked to the prevalence of lameness as well. One possible reason for reduced space causing an increase in lameness is the change in dunging patterns seen when space is restricted. Crowded pigs will dung in any place available (Gonyou et al., 1999) as opposed to using a separate discrete dunging area as seen in uncrowded pigs (Baxter, 1985a,b; Curtis, 1999). Thus, crowded pens accumulate feces in more places, creating slippery floors. When floors become slippery, the pigs are more likely to slip and injure themselves or become lame (Gonyou et al., 1999).

Restricted movement due to limited space may also be a cause of lameness. Dawkins et al. (2004) noted that fewer chickens housed at the highest stocking density showed good gaits. Since the birds were housed on litter-covered floors, the likeliness of lameness being caused by slippage was minimal. Thus, restriction of movement may limit the amount of time a bird (or pig) spends being active, which in turn increases joint stiffness, and eventually lameness.

Schmolke (2002) did not find an effect of group size on the number of pigs removed from the grow-finish trial for lameness. Overall, only 0.9 % of pigs were removed for lameness.

1.6.3 Tail biting

Tail biting is considered to be a behavioural disorder, or vice, that is perceived as the animals' reaction to an intolerable situation (Schroder-Petersen et al., 2004). Such situations may include the inability to perform normal behaviour patterns (frustration), or exposure to an intolerably high stress level (Schroder-Petersen et al., 2004). When exposed to frustrating situations, pigs will consequently redirect performance of feeding-related oral behaviour to penmate-directed oral behaviour (Lewis, 1999). It has been theorized that oral manipulation of penmates by one pig may cause others to begin biting as well (Lewis, 1999).

An outbreak of tail biting is not easy to prevent or cure because it can be influenced by numerous stress-inducing factors such as warm weather or high humidity (Schroder-Petersen et al., 2004). It was proposed that pigs with an altered behaviour pattern or appearance, such as those who are lame or sick, may be more interesting to bite or chew on (Schroder-Petersen et al., 2004). Furthermore, pigs who had already been tail bitten showed more signs of tail biting behaviour towards others (Keeling et al., 2004). Zonderland et al. (2004) found decreased tail biting when straw was provided to weaner pigs. Beattie et al. (1996) found that some other harmful social behaviours could be decreased by providing environmental enrichment.

In a survey of a number of herds, both Sundhed (2002) and Schroder-Petersen et al. (2004) found that the prevalence of tail bites was approximately 1.2 %, and occurred most often among pigs weighing 60 to 70 kg or more. Perhaps it is at that body weight that pigs are most easily influenced by stress. After mixing, the risk of tail biting occurring increased by 1.5 times, while risk increased by 3.5 times if the housing units did not provide bedding for the animals (Sundhed, 2002).

Occasionally, crowding has been shown to result in a higher incidence of behavioural problems (Gonyou et al., 1999). However, the majority of studies have found no effects of space allowance on the prevalence of tail biting when the pigs were crowded below a level of k = 0.027 (Brumm and NCR-89 Committee on Management of Swine, 1996; Goihl, 1996; Wolter et al., 2000c). A study carried out by the NCR-89 Committee on Confinement Management of Swine (1993) reported only one outbreak of tail biting in a crowded pen ($k = 0.024$) at one of the six stations involved in the study.

Holmgren and Lundelheim (2004) found that tail biting increased when group size increased from 8 to 12 pigs per pen. However, results of a study carried out by Schmolke et al. (2003) found tail biting damage scores were similar among larger group sizes of 10, 20, 40, and 80 pigs per pen, and increased at the end of the study in all groups. While studying similarly sized groups, Spoolder et al. (1999) recorded only one severe outbreak of tail biting, which occurred in a group of 20 pigs per pen, but overall they found no differences in the prevalence of tail biting between groups of 20, 40, or 80 pigs per pen. Wolter et al. (2000c) found no sign of abnormal behaviours like tail biting as a result of group size increasing from 20 to 100 pigs per pen.

1.7 Animal morbidity and mortality

Wilson et al. (1986) surveyed 27 randomly selected herds, totaling 1425 pigs, from the year 1982 to 1983. Findings indicated that the average feeder pig mortality rate was 3.4 % and ranged from 0.4 to 12.7 %.

Space restriction has been reported to decrease pig health and shorten life span (Freedman, 1975) by increasing the level of disease transmitted and contracted (Baxter, 1985b; Gonyou et al., 1999). Space restriction can increase stress levels, consequently increasing levels of inappropriate oral manipulation towards penmates or inanimate objects (Lewis, 1999). Chewing on floors increases manure ingestion with a resulting increase in bacterial ingestion. Subsequent chewing on penmates, or chewing on pen walls and partitions, may transmit disease from pig to pig or from one pen to another (Lewis, 1999).

Incidence of lung lesions ranged from 0 to 61 % in pigs crowded to $k = 0.030$, whereas only 1 % of uncrowded ($k > 0.080$) pigs experienced lung lesions (Holck et al., 1998). Stomach lesions can be debilitating or even fatal to pigs (Eisemann and

Argenzio, 1999). Crowding below $k = 0.026$ has been shown to increase or worsen stomach keratinization and ulceration (Burnham et al., 1995), especially if the pigs were fed finely ground feeds (Pickett et al., 1969).

Hale and Utley (1985) found a very high mortality rate of 17 % when pigs were crowded between $k = 0.015$ and $k = 0.019$. Such a high mortality rate can only be attributed to the extreme space restriction imposed upon the pigs in the study, which was likely compounded by the contraction of a number of ailments. Edwards et al. (1988) also found that more pigs failed to complete the trial when crowded to $k = 0.024$, but they stated that total removal incidences were too low to differentiate between treatments. When disease levels run high in the herd, performance is likely to be affected since sick pigs often stop eating, and thus, stop gaining weight.

Mortality level was not affected when grow-finish pigs were crowded to levels of $k = 0.027$ or $k = 0.024$ in studies conducted by Meunier-Salaun et al. (1987) and Brumm and Miller (1996), respectively. Similarly, Dawkins et al. (2004) reported no difference in chicken mortality levels when space was restricted.

Some studies comparing small (< 40 pigs/pen) to large (≥ 40 pigs/pen) groups of pigs have found no difference in pig morbidity (McGlone and Newby, 1994; Spoolder et al., 1999; Wolter and Ellis, 2002; Samarakone and Gonyou, 2003b; Schmolke et al., 2003), or mortality levels (Wolter et al., 2001; Wolter and Ellis, 2002). Others have found that morbidity levels did differ, and were higher among group sizes of 25 pigs per pen compared with 50 pigs per pen (Wolter et al., 2001). Randolph et al. (1981) suggested that the occurrence of increased aggression in larger groups may be the reason for increased morbidity in such groups. However, studies carried out by Spoolder et al. (1999) and Samarakone and Gonyou (2003a) did not find increased aggression in large groups compared with small groups. The main reason for pig morbidity according to Schmolke et al. (2003) was due to tail biting, while Spoolder et al. (1999) reported the highest incidence of removal was due to rectal prolapse (1.5 % pigs removed).

The findings of Schmolke (2002) indicated that morbidity levels totaled 5.7 % while Spoolder et al. (1999) found the total level to be 3.7 %. Wolter et al. (2000c) indicated that total morbidity of wean-to-finish pigs was less than 1 % in all group sizes.

Similarly, Wolter et al. (2000b) found that morbidity and mortality levels among wean-to-finish pigs totaled less than 1.5 % in each of the group sizes of 20 and 100 pigs per pen.

In well-planned research trials, animal health problems are often noted and treated at an early stage because assessment takes place at weighing when individual animals can be more readily evaluated, as well as during in-pen health checks. However, in commercial operations, injury assessment is not as focused at weighing, especially since it is becoming increasingly common for large groups of pigs to be weighed via an automatic system. Instead, in-pen health checks are relied upon for animal health assessments. Therefore, it is possible that differences in morbidity and mortality rates among differing group sizes in commercial operations may be a function of the ability of the barn staff rather than the intrinsic effects of group size. In other words, it may be more difficult to identify unthrifty pigs as group size increases due to reduced ease of observation of the stockperson who walks through the pen. Wolter et al. (2000c) stated that caretakers did, in fact, report having increased difficulty identifying and treating sick pigs housed in large groups of 100 pigs per pen compared with small groups of 20 pigs per pen. In contrast, if there are fewer pen dividers to climb over in larger groups, it should be easier for the stockperson to walk through the pen and identify problem animals requiring treatment. Based on personal experience, it is the author's opinion that, while climbing over fewer pen dividers does make health checking large groups less labourious, the vast number of animals to notice and individually assess makes health checking in large groups more complicated simply because there is increased difficulty in remembering which pigs you have already checked and which you have not.

1.8 Physiological parameters

A literature review conducted by Freedman (1975) suggested that stress due to crowding produces an increase in adrenal gland activity. When an animal is exposed to a stressor, the body responds by activating the hypothalamic-pituitary-adrenal axis, which results in elevated corticotrophin-releasing hormone (Hicks et al., 1998).

Corticotrophin-releasing hormone stimulates the brain's anterior pituitary to release adrenocorticotropic hormone and other peptides (Hicks et al., 1998). Elevated adrenocorticotropic hormone then stimulates the release of glucocorticoids, such as cortisol, from the adrenal cortex into the blood (serum) of the stressed animal (Hicks et al., 1998).

Approximately 90 % of cortisol in the blood is bound to protein (Cook et al., 1997). Bound cortisol appears to be physiologically inactive, with the primary purpose of supplying free cortisol to the tissues (Ganong, 1981). Cortisol concentrations can also be measured from urine and saliva. Generally, there is a good correlation between blood and salivary cortisol concentrations, but saliva sampling is less limiting because it is relatively easy to perform, does not require animal restraint, and can be achieved under conditions under which blood or urine sampling would be very difficult (Cook et al., 1997).

Free cortisol levels were 46 % higher and total plasma cortisol levels were higher as well among pregnant gilts housed in pens with a crowded space allowance of k = 0.036 or less compared with uncrowded (k = 0.072) pregnant gilts (Barnett et al., 1992). In a study conducted by Pearce and Paterson (1993), basal cortisol levels were not elevated by space restriction (k = 0.025), but growth was depressed. These results may be symptomatic of gradual onset chronic stress among those pigs. Perhaps the reasoning for the difference in the results of the two studies is because the assessment of basal cortisol concentrations have limited usefulness in terms of determining the degree of stress posed by the pigs' environment. A potentially more sensitive and reliable method of assessing environmental effects on adrenal activity may be the use of the exogenous adrenocorticotropic hormone challenge (Pearce and Paterson, 1993).

Injecting adrenocorticotropic hormone into the blood of an animal is a way of determining how stressed that animal may be because stressed animals are more sensitive to an increase in adrenocorticotropic hormone in their blood (Pearce and Paterson, 1993). In other words, stressed animals subjected to an adrenocorticotropic hormone 'challenge' will respond by increasing their output of cortisol more rapidly. It has been suggested that responsiveness of the adrenal glands to an adrenocorticotropic hormone challenge in poultry may be useful in monitoring a bird's adaptation to stressful situations (Post et al., 2003).

In the study carried out by Pearce and Paterson (1993), crowded pigs ($k = 0.025$) did, in fact, respond with higher peak cortisol levels than uncrowded pigs when exposed to an adrenocorticotropic hormone challenge. Results of the adrenocorticotropic hormone challenge suggest that the crowded pigs may have been chronically stressed. Meunier-Salaun et al. (1987) also suggested that pigs housed under crowded conditions ($k = 0.027$) may have been experiencing chronic, or long-term stress because they had a higher adrenal sensitivity to an adrenocorticotropic hormone injection.

Analysis of an animal's adrenal glands can also give some idea of the level of stress that the animal had undergone while it lived. The glands of stressed animals would be larger and heavier since they had been more active in releasing cortisol (Freedman, 1975). However, there are studies that have found no effects of space allowance on cortisol levels or adrenal gland weights. Cortisol level and adrenal response after an adrenocorticotropic hormone injection were not affected among heifers housed at space allowances of $k > 0.035$, $k = 0.029$, or $k = 0.023$ (Fisher et al., 1997a). Horton et al. (1991) found no effects of space allowance on cortisol levels in grower lambs restricted to $k = 0.027$, 0.046, or 0.073. Similarly, there were no differences in the right adrenal gland weights of heifers when crowded at $k = 0.023$ (Fisher et al., 1997b).

Often times, studies that require pigs to experience increased physical or visual human contact for sample collection or other data collection may increase stress levels among those pigs. Therefore, salivary or blood plasma cortisol levels and adrenal weights may be affected due to factors other than what is being studied.

Effects of group size on pig stress levels are not widely studied, especially among group sizes of over 40 pigs per pen. Total corticosteroid concentrations were higher for gilts housed in pairs than for those housed in groups of 4 or 8 pigs per pen (Barnett et al., 1986). A sustained increase in plasma free-corticosteroid concentration among gilts housed in pairs indicated that those animals underwent a chronic stress response (Barnett et al., 1986). Samarakone (personal communication) found no differences in salivary cortisol concentrations between pigs housed in groups of 18 versus 108 pigs per pen.

It has been hypothesized that increasing group size would increase aggression (Baxter, 1985b), which may decrease health status and increase stress (Freedman, 1975). Examination of adrenal glands would be a valuable indicator of the degree of stress, namely chronic stress, that an animal had undergone during its life. However, Samarakone (personal communication) did not find any differences in the weights of adrenal glands, or the cortex:total gland area ratio, in large groups (108 pigs per pen) compared with small groups (18 pigs per pen). Further studies are needed to determine the effects of group size, both large and small, on pig stress levels.

As population size of voles (*M. breweri*) increased, so did the weight of their adrenal glands (To and Tamarin, 1977). However, in a population of *M. pennsylvanicus* voles, adrenal weight did not increase with increased population density (To and Tamarin, 1977). This suggests that increased adrenal weights due to increased population density may be species specific in voles. If species differences are evident, could breed differences be possible too, and could these differences be seen in pigs? Future studies should be aimed at determining whether there are breed effects on adrenal gland sizes when pigs are housed at varying population sizes.

1.9 Carcass measurements

Since reduced space allowance has been shown to affect production variables such as daily gain and feed intake, then one would assume that certain carcass measurements would also be affected. Carcass measurements such as back fat thickness, lean gain and carcass weight are the variables most likely to be affected when daily gain and feed intake are reduced due to crowding.

Fat and lean gain for crowded pigs (k = 0.030) was only 70 % that of uncrowded pigs, resulting in lower back fat and loin eye area depths (Holck et al., 1998). Burnham et al. (1995) and Brumm and NCR-89 Committee on Management of Swine (1996) also found that pigs that had been crowded (k = 0.024) produced lower levels of back fat. In another study, crowding pigs from the nursery (k = 0.021) through to the end of the finishing phase (k = 0.024) caused a decrease in daily lean gain, but not carcass lean percentage (Brumm and Miller, 1996).

Alternatively, back fat levels were not affected by crowding in the studies carried out by Hugh and Reimer (1967) or Edwards et al. (1988). Pigs housed at k = 0.025 tended to have lower rib fat depths, but those differences were not statistically significant (Brumm and NCR-89 Committee on Management of Swine, 1996).

Hamilton et al. (2003) found gender and space allowance interactions for leanness, stating that gilts were leaner in the crowded environment (k = 0.021) while barrows were leaner in the uncrowded environment ($k > 0.035$). These results warrant further studies examining the effects of space allowance on carcass lean gain and carcass lean percentage among the genders.

In group size studies, carcass measurements taken from live animals housed in groups of 25, 50, and 100 indicated no differences in back fat or loin depth (Wolter et al., 2001). An ultrasonic scanning probe measured back fat and loin depths on live pigs the day each pen was taken off test (Wolter et al., 2001). Measurements taken postmortem also indicated no difference in back fat or loin eye measurements, or for carcass yield or predicted carcass leanness, between group sizes of 25, 50, and 100 (Wolter et al., 2001). Similarly, Samarakone (personal communication) found no differences in back fat, lean depth, predicted percentage lean, or dressed weight percentage between groups of 108 and 18 pigs per pen.

1.10 Gender

Up until approximately 45 kg body weight, differences in gains between the genders are almost negligible (English et al., 1988). From that point on, the gains of boars are far superior to gilts and barrows (English et al., 1988). Barrows were found to grow significantly faster (Pickett et al., 1969; Jensen et al., 1973; Hyun and Ellis, 2001; Samarakone and Gonyou, 2003b) and have higher final live weights than gilts when allowed to grow for the same period of time (Schmolke et al., 2003), and this is most noticeable past 55 kg live weight (English et al., 1988). Gilts experience a greater degree of variation in body weight than boars (Hanrahan, 1981). When space restrictions were imposed upon the pigs, Gonyou (1999) found that reduced daily gain was particularly evident in barrows. This suggests that the faster growing barrows may be more susceptible to stress due to crowding, and thus, more affected than gilts when space restrictions are imposed.

In terms of fat and lean gains, barrows deposit fatty tissue at a faster rate than gilts from 48 to 90 kg live weight (English et al., 1988). As a result, barrows have a higher fat content than gilts. Hamilton et al. (2003) stated that gilts were leaner when housed in crowded environments (k = 0.021) while barrows were leaner when housed in uncrowded environments (k > 0.035). At slaughter, gilts had higher hot carcass weights, higher dressing percentages, lower fat depths at the last rib, 10^{th} rib, and last lumbar vertebra, and a larger loin eye area compared with barrows (Hamilton et al., 2003).

There have also been reports of one gender experiencing a higher level of injuries than the other. In a study carried out by Partanen et al. (2004), it was found that lameness was 1.60 times higher in barrows than in gilts.

It is important to consider the effects of gender on performance when reviewing past research, as some studies have used split-sex allocation to treatments while others have used single sex allocations.

1.11 Space allowance x group size interactions

Any space provided to an animal must accommodate the animal's body size and leave some space for movement (referred to as free space). In group housing, free space is shared. Increasing group size increases the amount of free space available to the pigs (Bryant and Ewbank, 1972; McGlone and Newby, 1994). Therefore, when all but one animal is lying down, the active animal has free use of a much larger space than if it was housed individually (Bryant and Ewbank, 1972). It has been hypothesized that, since the amount of free space available is greater in large group housing, it may be possible to decrease total floor space (and thus free space) without negatively affecting pig performance (McGlone and Newby, 1994).

Gonyou and Stricklin (1998) found that, by restricting the space allowance (k = 0.030) provided to group sizes of 3, 5, 6, 7, 10, and 15 pigs per pen, both gain and feed intake were negatively affected. Group sizes in their study were somewhat standard in terms of commercial operations, but could not be considered large groups. Therefore, the hypothesis that group size can be increased without negatively affecting performance can be disregarded because free space was not significantly increased with increasing group size in the Gonyou and Stricklin (1998) study. Furthermore, the authors stated that their study provided minimal replication for accurate analysis of group size x space interactions, and suggested a much larger study to resolve this problem.

Studies assessing the interactions of large groups (> 40 pigs per pen) and space allowance are very few. Although they do exist, the small number of studies conducted have occasionally confounded group size with space allowance (Wolter et al., 2002), or with feeder space per pig (Wolter et al., 2003).

Wolter et al. (2000c) reported an interaction of group size and space allowance in their wean-to-finish study. In week 1, crowded pigs (k = 0.030) housed in groups of 100 had a poorer feed efficiency than their uncrowded counterparts. However, in groups of 20 pigs per pen, the crowded pigs were more efficient than their uncrowded counterparts. This was the only significant interaction of group size and space allowance throughout the study, and it should be noted that the interaction seen was only seen during the weaner period. There were no effects of the treatments on gain or feed intake, and no signs of abnormal behaviour such as tail or ear biting.

Since the findings of Wolter et al. (2000c) indicated similar levels of performance at reduced space allowances for groups of 20 and 100 pigs per pen, even though actual floor space was 13 % lower (50 % less free space) for the larger group size, the hypothesis put forth by McGlone and Newby (1994) has some support. Pigs housed in large groups may be able to achieve maximum growth given less floor space, provided that large-group housed pigs are given no less than 50 % of the free space provided to their small-group housed counterparts (Wolter et al., 2000c). Such findings, and the fact that group size x space interaction studies are few, warrant further probing into the effects of housing pigs in large groups at restricted space allowances.

1.12 Conclusion

The pressure put on commercial livestock operations to become more economically efficient is increasing. As Webster (2001) stated:

> Although the moral imperative may be to improve husbandry out of respect for the intrinsic value of farm animals, it is, unfortunately the extrinsic value of the animal that determines the quality of husbandry that the farmer can afford.

Many producers find themselves attempting to fit one more pig into an already full pen. Yet, restricting the space allowance provided to animals has been proven to have many detrimental effects on animal productivity, health and welfare. This issue has raised many public concerns.

Large group housing for pigs is becoming increasingly common in the intensive livestock industry. This may be due, in part, to the lower costs associated with reduced inputs required for large group housing. A great deal of literature to date states that pigs are able to live in some degree of harmony in such groups and experience minimal production losses, most of which occurs early in their lives. But literature on how pigs respond to space restriction when housed in large groups is limited, as is the effects of such housing on their health and welfare. While some researchers have hypothesized that pigs may be able to use limited space more efficiently when housed in large compared with traditional small groups, others are skeptical. The following study has been designed to address the question of space use in large groups, and to determine how pigs respond to space-restricted large group housing in terms of variations in productivity, health, and welfare status.

2. THE EFFECTS OF HOUSING GROW-FINISH PIGS AT TWO DIFFERENT GROUP SIZES AND SPACE ALLOCATIONS ON PERFORMANCE, BEHAVIOUR, HEALTH AND WELFARE

2.1 Introduction

With the shift of hog operations to housing pigs in groups of over 100 pigs per pen come questions as to how these pigs should be managed. First and foremost, does the space requirement of pigs raised in this type of housing differ from that of pigs raised using traditional group sizes? It is not known whether large groups of pigs require the same amount of space as their small group counterparts, or whether they can perform as well, or better, under reduced space allowances. McGlone and Newby (1994) hypothesized that pigs housed in large groups would be able to use space more efficiently since they have access to a greater amount of free space than pigs housed in small groups. Because of this fact, they also hypothesized that as group size increases, total space can be reduced without negatively affecting performance. Space recommendations put forth by the AAFC (1993) have been based on traditional group sizes, which tend to range from 1 to 40 pigs per pen. Therefore, this study has been designed to assess the space requirements of both large (108 pigs) and small (18 pigs) groups of pigs with the objective of determining the critical point at which gains are affected by reduced floor space in each group size, and the rate at which this depression in gain occurs. Furthermore, the effects of group size and space allowance on performance, behaviour, physiology, health and welfare over time were examined.

2.2 Materials and methods

The following study looked at the effects of housing grow-finish pigs in groups of 18 or 108, provided with either 0.78 m^2/pig or 0.52 m^2/pig of floor space, in eight complete blocks.

2.2.1 Experimental design

The experiment consisted of eight blocks. Each of the rooms used in the study was considered as one block. Two blocks (two rooms) were initiated approximately one week apart, and this was repeated four times, creating the total of eight blocks. Each block consisted of a 2 x 2 factorial arrangement of small (18 pigs/pen) versus large (108 pigs/pen) group sizes, and crowded (0.52 m^2/pig) versus uncrowded (0.78 m^2/pig) space allowances, creating four experimental treatments (units): small crowded, small uncrowded, large crowded, and large uncrowded (Figure 2.1). In each block there were four small pens (two crowded and two uncrowded) as well as two large pens (one crowded and one uncrowded). Two adjacent small pens were always equal in treatment because the feed system was set up to feed them in pairs. Therefore, they were considered one experimental unit. In summary, one large pen of 108 pigs was considered one experimental unit while two adjacent small pens of 18 pigs each (36 pigs total) was considered one experimental unit. Pens for the uncrowded treatments were reduced in size by the use of a temporary spindled partition to create the crowded treatment. Prior to each block, the location of treatments was randomly allocated to account for possible environmental differences within the grow-finish rooms. Therefore, the method used followed a randomized complete block design.

Space allowance was determined using an allometric equation: $A = kBW^{0.667}$ (A = area in m^2, k = space coefficient, BW = body weight of the pig in kg). This method defines space allowance in terms of the 'k' value. Although the k value decreased as the pigs grew, the floor space allowance for the uncrowded treatment was chosen to provide $k > 0.035$ ($m^2/BW^{0.667}$) throughout the study. However, for the crowded treatment pigs, floor space allowance became much more restricted as they grew. The space allowance

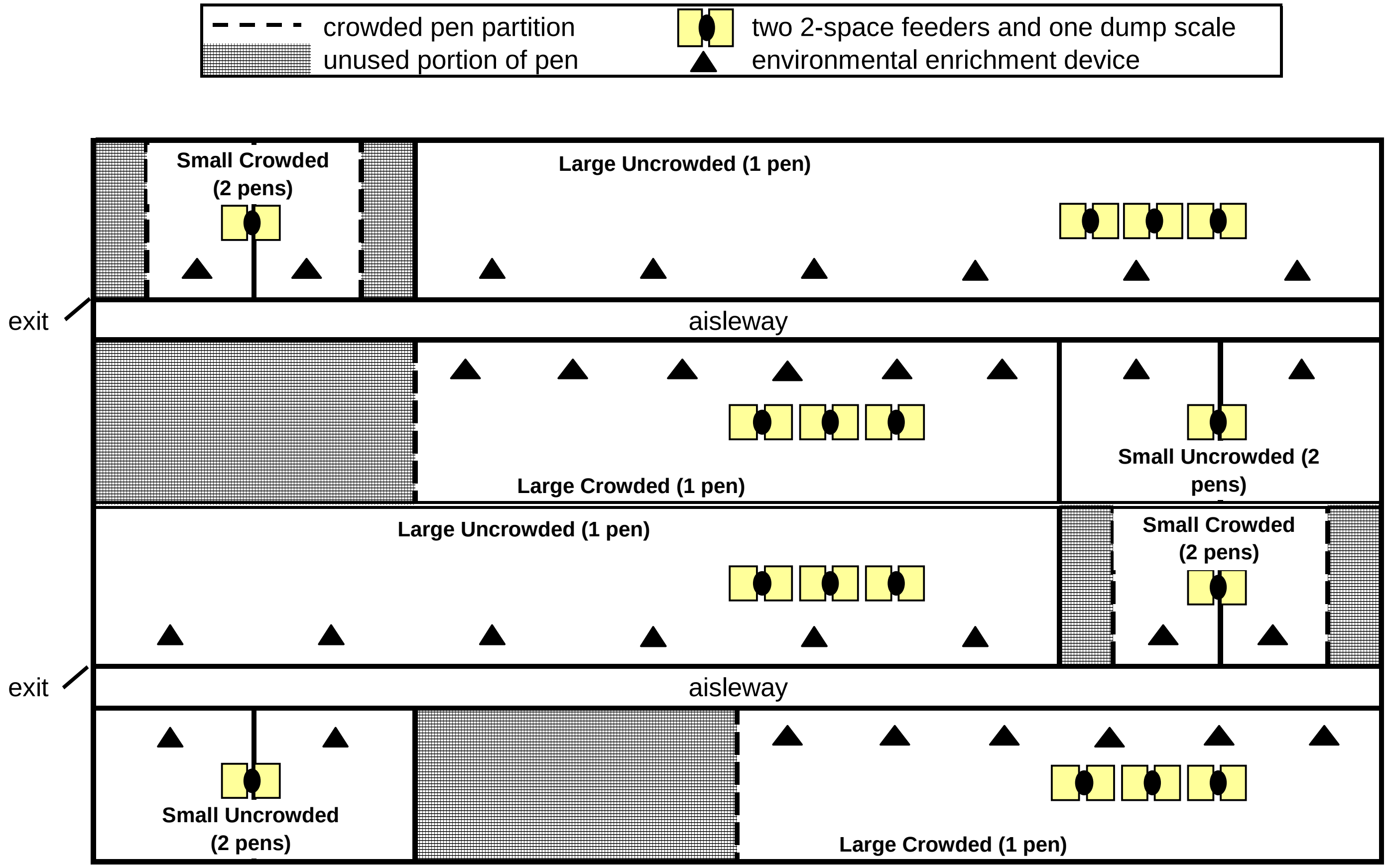

FIGURE 2.1 Example set up of two blocks (rooms) running simultaneously. Treatments were rotated within each block when the rooms were filled with new pigs. Diagram is not to scale. Small crowded pens were 5.8 m x 1.6 m, small uncrowded pens were 5.8 m x 2.4 m, large crowded pens were 9.8 m x 5.8 m, and large uncrowded pens were 14.5 m x 5.8 m.

chosen provided k = 0.035 at an average body weight of 55 kg; k = 0.028 at a body weight of 75 kg; and k = 0.025 at a body weight of 95 kg. The k values at which these weights occurred increased slightly if pigs were removed from a test pen. Therefore, regardless of treatment and not counting the space occupied by the feeders, crowded pigs were provided with 0.52 m^2 of space per pig and uncrowded pigs were provided with 0.78 m^2 per pig. Space allowance was not adjusted during the study in order to resemble space management that would be typical of commercial situations. Previously established animal care guidelines were used to terminate each replicate when the crowded k reached 0.025 (i.e. body weight of 95 kg if no pigs had been removed from the pen).

Each block lasted for 84 days except for block seven, which lasted for 91 days due to initial difficulties in obtaining enough pigs for the block. A habituation period was allotted for each block, prior to the initial weighing, so the pigs could become accustomed to their new environment. The habituation period lasted for three or four days. All of the pigs in a particular block were allocated to treatments on the same day (day -3 or -4). An exception occurred for block seven. For that block, 231 pigs were randomly distributed among the treatments on day -12. On day -5, the remaining 57 pigs (totaling 288 pigs in the block) were randomly distributed among the treatments in a way that allowed for the correct number of pigs per treatment to be assigned. This setback occurred due to overlap with another unrelated study, which caused an initial shortage of pigs and a delay in the pig distribution process. The test start day, which was the initial weigh day, was considered to be day zero. The test portion of the study lasted for 49 days (blocks 1, 2, and 7) or 56 days (blocks 3, 4, 5, 6, and 8). The test period ended when the crowded pigs reached k = 0.025. The block duration (84 or 91 days) included the habituation period, the test portion of the study, and the marketing period after the test portion of the study concluded.

We attempted to market the pigs at a specific body weight in order to standardize the carcass weights and thus, carcass measurements such as back fat and lean depth. Therefore, during the final test weigh period (average body weight of 95 kg), we began to mark the pigs for market based on predicted gains for the following two-week period.

Eight pigs from each experimental unit were randomly selected and individually identified as focal pigs by use of a coloured, numbered ear tag on one ear. These pigs were tagged in order to more easily identify them during subsequent sampling and observation. Tagging was carried out the day the room was filled (upon allocation to treatments).

2.2.2 Facilities

The study was carried out in two artificially ventilated, fully slatted grow-finish rooms at the PSC Elstow Research Farm. Room ventilation was thermostatically controlled to maintain thermoneutral temperatures, except during weather exceeding 25 ˚C. Room temperature was recorded twice per day: once in the morning and once in mid-afternoon. Lighting was kept on a consistent 12:12 bright:dim cycle to allow for behavioural observations at night. Pen partitions were spindled, but gates/penning along the central alleyway were made of solid interlocking PVC panels. The manure system used was a gravity pit system in which pit plugs were manually lifted in order to empty slurry from the pits. This was carried out whilst the rooms were empty (prior to filling them with a new batch of pigs).

Feed and water were supplied ad libitum in two-space wet/dry feeders (Crystal Springs, Ste. Agathe, MB), which were provided at a rate of one space for every nine pigs. Water was not provided elsewhere. Feeder spaces were 32 cm wide with well defined shoulder protection. In the large groups, all six feeders (12 feeding spaces) were contiguous near one end of the pen and arranged to provide two rows of six spaces each. In adjacent small groups, the feeders were side by side. Each pair of feeders was equipped with a calibrated weight-based dump scale (Brehmer Manufacturing, Lyons, NE), which weighed the feed during filling of the feeder. The dump scales were calibrated and rotated weekly during blocks one and two, and bi-weekly during the remaining blocks to ensure accuracy and equality among treatments. Feeder and dump scale set up can be seen in Figure 2.1. Feed was supplied via an automated system. Feeder openings were scraped twice daily with a metal hook to ensure that they were not plugged.

Environmental enrichment in the form of "Bite rite" toys (AM Warkup Ltd., Lisset, UK) was provided at a rate of one toy for every 18 pigs. The toys were distributed evenly in the front third of each pen (Figure 2.1). Each toy was equipped with four chewable plastic rods.

2.2.3 Animals

The study used 2304 pigs (Pig Improvement Company, sow line C22 or C42, boar line 337) from the minimal disease herd. Each block consisted of 288 pigs. A preliminary study (first two blocks) consisting of mixed sex pens (equal numbers of barrows and gilts) was conducted to specifically examine production parameters. The remaining six blocks used only castrated male pigs, and examined physiological, health, and behavioural parameters in addition to production parameters. The decision to use only castrated males for the final six blocks of the study was due to specifications set by the National Pork Board, which agreed to fund the trial after the preliminary study.

The animals were weaned at three weeks of age and housed in nurseries for seven to eight weeks until they were moved to the grow-finish area of the barn at 10 to 11 weeks of age. Due to the fact that a large number of pigs of a single sex were needed at the beginning of each block, pigs born within a three-week period were selected and used for each block within the study. The animals were randomly allocated within age groups to ensure a random distribution of weights and ages within each treatment. The pigs were put onto test at an average initial body weight of 38.01 kg, 38.02 kg, 36.55 kg, and 36.97 kg (± 0.37 kg) for the small uncrowded, small crowded, large uncrowded, and large crowded groups, respectively. The average final weight of the animals at the conclusion of the test portion of the study was 96.21 kg, 93.95 kg, 93.10 kg, and 91.29 kg (± 0.57 kg) for the small uncrowded, small crowded, large uncrowded, and large crowded groups, respectively.

2.2.4 Diets used

A mash diet was nutritionally balanced according to NRC requirements and fed throughout the study (Table A.1). The diet was fed in three phases, with each phase designed to meet the needs of the pigs at the corresponding stage of growth. The primary energy source was wheat while the primary protein source was peas. Barley and corn were also used as energy sources, and canola and soybean meal were used as additional protein sources. The amount of ingredients in the diet varied somewhat over time because the diets were formulated to achieve the desired nutrient balance using the least expensive combination of ingredients at the time of mixing.

2.2.5 Data collection

The first two blocks acted as a preliminary study in which only production data was collected. Production data collected included daily gain, daily feed intake, and injury assessments at the start and end of the study. The remaining six blocks were also used to collect production data, as well as assess behavioural, physiological, health and welfare parameters.

2.2.5.1 Productivity

Pigs were weighed on a weekly basis to determine instantaneous and cumulative impacts of crowding on pig growth. To equalize weight loss due to urination and defecation between small and large groups of pigs, the pigs were moved to the scale in groups of 18. This decreased the waiting period that would normally occur at the scale, and thus, minimize any immediate weight loss in the large groups. Pigs were weighed individually the day they were put onto test (day zero) as well as the day they were taken off test (day 49 or 56, depending on the block). Otherwise, pigs were weighed in groups of six and the weights were averaged to give the average pig weight for each pen. Gains were calculated using that average pig weight and the average pig weight from the previous weighing, then divided by the number of days between weighings.

Feed additions were recorded daily so that feed intake and efficiency could be calculated on a weekly basis. Feed was weighed by calibrated, weight-based dump scales (Brehmer Manufacturing, Lyons, NE) prior to entering the feeder. The automated feed system was set up in such a way that fed adjacent small pens in pairs.

Some problems occurred with the automated feed system throughout the trial. On a number of occasions, the line did not provide enough feed to fill the feeders overnight and the pigs went without feed for a short length of time. On a small number of occasions, the dump scales malfunctioned. Therefore, it was necessary to discard data on some days in order to maintain an accurate prediction of feed intake.

2.2.5.2 Behavioural time budgets

2.2.5.2.1 Feeding behaviour

In order to examine feeder usage over time, video cameras monitored groups of feeders for a 24 hour period bi-weekly throughout the study. In the large pens, the front six feeder holes and the rear six feeder holes were monitored by separate cameras. Feeders in adjacent small pens (total of four feeder holes) were monitored by one camera. Prior to videotaping, livestock paint was used to mark the back of each focal pig with a number. Only data for the focal pigs were recorded during the 24-hour videotaping periods.

Video-recording of the feeders enabled continuous observation of feeding behaviours, or more specifically, examination of the frequency and duration of feeding events, and the latency between every feeding event, for each focal pig. The start of a feeding event was defined as the focal pig putting its head into a feeder. When the pig removed its head from the feeder, the feeding event was considered to be over. For sake of ease, the length of feeding events were truncated to minutes so that meals lasting less than 59 seconds were recorded as zero minutes, meals lasting 60 to 119 seconds were recorded as one minute, meals lasting 120 to 179 seconds were recorded as two minutes, and so on.

By analyzing a frequency distribution of the number of eating bouts in a 24-hour period, it was seen that pigs participated in a large number of eating bouts within a six-minute interval. After six minutes, the number of bouts diminished greatly. Therefore, a bout criteria interval of six minutes was used to establish the number of 'meals' for each animal (as described by Lehner, 1979). Meal duration was the amount of time a pig spent eating during a meal and total meal duration was the total amount of time that a pig spent eating in a 24-hour period, again using the bout criteria interval of six minutes (Lehner, 1979). The proportion of time spent by pigs at the feeder was also calculated using 24-hour live observations. These methods are explained in more detail in the following section (see 2.2.5.2.2 Postural behaviour).

For the first two blocks (the preliminary study), videotaping of feeders was not carried out. For blocks three through eight inclusive, feeding behaviour observations were made through use of a time-lapse VCR (Panasonic AG6730 or AGTL950). Added lighting in the form of one 100 Watt incandescent light bulb was situated above each set of feeders, totaling one bulb per treatment. During blocks 4, 6, and 7, videotaping occurred simultaneously with 24-hour postural behaviour observations.

2.2.5.2.2 Postural behaviour

Behavioural observations employed methodology described by Martin and Bateson (1993). The observations were carried out by trained observers at bi-weekly intervals throughout blocks three through eight. There were three sets of observations per block (four sets in block eight only). Each observation consisted of instantaneous scan sampling of each pen at 20 minute intervals throughout a 27 hour period. The first three hours of each observation period was conducted so that the pigs could habituate to the presence of an observer in the alleyway, and the data were not used in statistical analysis. The remaining 24 hours were segmented into eight-3 hour periods.

Throughout the observation period, an observer had 20 minutes to complete one rotation, which consisted of 12 pens (six pens in each of two rooms). The observer would remain in the aisleway and travel from pen to pen recording a tally of each body position of the pigs within the pen. The tally consisted of the number of pigs lying ventrally (lying with the sternum in contact with the floor), sitting (supported by two legs; resting on rear end), standing (supported on four legs but not eating), and eating (head in the feeder). Each type of behaviour recorded was considered to be mutually exclusive. The number of pigs lying laterally (on their side) was not tallied and recorded at the time of live observation because the value could be calculated later by subtracting the total of the other body positions from the total number of pigs in the pen. For large pens, scan samples were made of well-defined regions and then summed to obtain total pen values for that posture. An observer would observe in this manner for a two hour period followed by a one hour break, providing 16 hours of observation in a 24 hour period (18 of 27 hours when including the habituation period).

During blocks 4, 6, and 7 the 24-hour postural behaviour observation period occurred simultaneously with the 24-hour videotaping period. Therefore, there was added light during these observation periods in the form of four 100 Watt light bulbs, provided at a rate of one bulb per treatment, situated over the feeders. The added light was necessary for videotaping because the cameras were not capable of collecting data in the dark. Since observations were carried out bi-weekly throughout the test period, it could also be determined whether activity patterns were influenced by a difference in age (body size) within each group size and space allocation.

2.2.5.3 Injury scoring

On a bi-weekly basis and at the same time as weighing, the pigs were assessed for injuries, including tail bites, flank bites, leg lesions, and lameness (Table 2.1). A score of zero was given if there was no evidence of the injury in question, and the score increased as the severity of the injury increased. A record of the presence of a fluid filled bursa on one or both elbow (olecranon) joint(s) was also made.

Injury scoring was carried out by a total of four individuals, each trained by the main researcher. The same individual carried out scoring throughout each set of two blocks in order to keep scores relatively consistent. For blocks one and two, this method of injury scoring was only carried out on the first and last day of test. For the remaining blocks (three through eight, inclusive), injury scoring was carried out as outlined above.

TABLE 2.1

List of injury scores and their corresponding meanings

Type of Injury	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 favour 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	N	no bursa present
	Y	presence of one or both leg bursa on olecranon joint

2.2.5.4 Animal morbidity

All animals used in the experiment were in excellent health and free of potentially debilitating injuries upon commencement of the study. A trained technician carried out health checks twice daily by entering each pen and getting all of the pigs up and moving. Sick or injured animals were identified at health checks and treated as needed. When treatment was required, medication was administered intramuscularly in the neck just behind the ear. Animals found dead and animals in need of isolation as a result of their illness were removed from the study. Body weight and a detailed reason for removal were recorded for each animal removed from the study.

2.2.5.5 Salivary cortisol concentrations

Saliva samples were taken from focal pigs bi-weekly in blocks three through eight inclusive, in alternate weeks to that when the postural behaviour observations were made. In total, saliva samples were collected four times throughout each block (see Tables A.2 and A.3 for sampling week occurrences and corresponding mean weights, respectively). Sampling took place between 1200 and 1400 hours to reduce diurnal variation in cortisol levels. Two samplers remained in the pen until sampling was complete, at which time they moved to the next pen. A sampler would attempt to collect a sample for no more than two minutes per pig so that the pig would not be stressed by the sample collection procedure itself. If the pig continuously evaded the sampler in the two-minute sample period allowed, that pig was skipped and no sample was obtained. A stopwatch was used to time the sampling of each pig, and the duration was recorded.

Past experience had proven that pigs would chew on an absorbent cotton wad attached to the end of a stick held close to their mouth. During the first two sampling periods, this was how the saliva samples were obtained. During the remaining sampling periods, a combination of the stick method and manually placing the wad into the animals' mouths was used in order to minimize the time spent in each pen. The wads were then centrifuged and the liquid portion was transferred to a new vial. The samples were then stored frozen until further laboratory analysis could be carried out.

Prior to laboratory analysis, some of the samples were thawed and combined. The samples that had been obtained in under five minutes from entry into each pen, within each block and week, were combined to create one sample. As a result, there were two samples for each small group treatment, and one sample for each large group treatment for each week in each block. After the combination process had occurred, the samples were refrozen. Samples obtained within the first sampling week were not combined. Instead, the samples remained frozen for analysis of time effects on sampling. Saliva samples were analyzed for salivary cortisol concentrations. The cortisol concentration of each sample was analyzed in the lab of Nigel Cook in Lacombe, Alberta using a competitive enzyme immunoassay. The methodology described by Cook et al. (1997) was used.

2.2.5.6 Post mortem adrenal gland analysis

Prior to slaughter, two of the previously identified focal pigs were randomly selected from each of the four treatments within a block. For the small groups, one pig was selected from each of the two pens. The animals were sent to slaughter, regardless of body weight, six days after the crowding partitions were removed in blocks 3, 5, and 6, eight days after the crowding partitions were removed in blocks seven and eight, and 13 days after coming off test in block four.

At slaughter, the adrenal glands from the randomly selected focal pigs were collected. Glands were only collected from pigs in blocks three through eight, inclusive. In the laboratory, the glands were dissected out of the surrounding layers of fat and connective tissue, and the weight of each gland was determined. They were then fixed in vials of 10 % formalin solution.

The left adrenal gland from each animal was sent to the Prairie Diagnostics Laboratory at the Western College of Veterinary Medicine. There, the glands were cross-sectioned in the mid-section of the gland, mounted on a slide, and stained with a Grimelius stain so that the areas of the cortex, medulla, and the total gland area could be measured and ratios calculated. The ratio of the medulla to the cortex, in particular, is indicative of the level and duration of stress the animal experienced while alive.

The live body weight of the pigs taken the day the crowding partitions were removed ('off test') in a block was used to calculate the ratio of the left adrenal gland weight to live body weight. The live body weight of the pigs in block four was increased by 6 kg because the latency between the removal of the crowding partitions and slaughter of the pigs was five to seven days longer than the latency in the other blocks. It was estimated that 6 kg would be gained by the pigs during the extra five to seven days, so that weight was added to their off test body weights to ensure equality among the treatments when gland weight:body weight ratios were calculated.

2.2.5.7 Carcass measurements

When the crowded treatment reached k = 0.025 in a room (block), we began marking pigs for market. This meant that, on weigh days, pigs that were predicted to reach market weight within the following one or two weeks were marked accordingly with livestock paint, then sent back to their home pen. On the day before shipping, pigs that were predicted to have reached market weight were shoulder tattooed according to their block and pen. In blocks one and two, pigs were shoulder tattooed according to their block, pen and gender. They were then sorted out of their home pen and moved into new pens in the load-out room, which often required mixing of pigs from the different treatments. In the load-out, the pigs were fasted overnight but allowed ad libitum access to water.

The following day, the pigs were shipped by semi-trailer to the slaughter plant. At the plant, it was the responsibility of the slaughter line workers to record the appropriate tattoo and collect data on each carcass. The carcass data recorded that would later be used in statistical analysis included carcass value index, percent lean yield, fat depth, and lean depth. Fat and lean measurements were taken between the third and fourth rib (loin) on the left side of the pig, and the two measurements were used to calculate the percent lean yield. Carcass value index was calculated from the percent lean yield and the carcass weight of the pig. Only data from the first 50 % of pigs that went to market were collected so that compensatory gains following removal of the crowding partitions would be minimized.

Due to welfare standards set by the Animal Care Committee, pigs in a crowded treatment were only crowded until they reached a value of $k = 0.025$. At that point, the crowding partitions were removed from the pen and the pigs were allowed access to the same amount of space provided to the uncrowded treatments. However, at $k = 0.025$, the average pig body weight was only 95 kg and did not meet market weight requirements. Carcass measurement data were considered secondary to production and physiology data and so pigs were held back from market until they reached market weight. The time period required for the first 50 % of the pigs to reach market weight (i.e. the number of pigs from which carcass measurement data were analyzed) was up to 41 days after the crowding partitions had been removed. Since literature on compensatory carcass gains is minimal, it is not known how this latency-to-marketing affected the carcass measurements of crowded treatment pigs. However, the group size treatments remained intact up until the pigs were marketed and therefore, gave accurate carcass measurement data on how a pig's body responds to being housed in small or large groups.

2.2.6 Statistical Analysis

There were two group sizes (small and large) as well as two crowding treatments (crowded and uncrowded). There were eight blocks in total, with each of the four treatments (small crowded, small uncrowded, large crowded, and large uncrowded) occurring equally within each block. The allocation of treatments within each block was carried out using a randomized complete block design. All statistical analyses were carried out using SAS statistical software system for Windows (SAS Inst., Inc., Cary, NC).

When individual animal data were available from blocks one and two, gender was treated as a sub-plot within the treatment. If the interaction effects of gender were significant, then the data were reported as such, but gilt data were disregarded in further analyses. If the interaction effects of gender were not significant, then they were reported as such but the genders were combined to create a treatment average for further analysis.

All variables were tested for normality by analysing the residual dataset using the univariate procedure in SAS, with the exception of animal morbidity data. Morbidity data were analyzed using the GENMOD procedure, which employs a non-parametric methodology. Therefore, the data analyzed by this method did not need to be tested for normality. If a variable tested for normality was not normally distributed, the raw data were then transformed using the Microsoft Excel program. Raw data were used in tables and figures, but *P*-values represented the significance of the corresponding transformed data. The type of transformation used for a variable is specified in the statistical analysis section for that variable. The ANOVA model used in normality testing is shown in Table 2.2.

2.2.6.1 Gender

The interaction effects of gender and space allowance or group size were computed using the general linear model in SAS for body weights and the corresponding coefficients of variation, overall average daily gain, carcass measurements, and initial and final injury scores. This analysis was only carried out on data from blocks one and two, as it was only these blocks that housed both barrows and gilts. Table 2.3 represents the ANOVA model used in the analyses.

2.2.6.2 Productivity

The productivity variables evaluated were daily gain, daily feed intake, feed efficiency (daily gain:daily feed intake), and the coefficient of variation values for initial and final body weights. For blocks one and two, each analysis used an average of barrow and gilt data within their respective treatments.

The MIXED procedure was used to analyze daily gain, daily feed intake, and feed efficiency by week, using week as a sub-plot within the treatments. Data from all eight blocks were used in the analysis. The ANOVA model used follows that shown in Table 2.4. The data were also statistically analyzed for treatment effects within each week, and over the entire duration of the study. The ANOVA model for this data is

TABLE 2.2

ANOVA model used for standard statistical analysis[1,2]

Variable	df	
Block	7	Compared to Error Term 1
Group Size (GS)	1	Compared to Error Term 1
Space (Sp)	1	Compared to Error Term 1
GS*Sp	1	Compared to Error Term 1
Block (GS*Sp)	21	Error Term 1

[1]Model used in analysis of initial and final body weights, carcass data, and adrenal gland analysis, and used for within week analysis of daily gain, daily feed intake, feed efficiency, injury scores, and postural behaviour observations

[2]Only 6 blocks were analyzed for injury scores within week, carcass data, postural behaviour data, and adrenal gland analysis. Therefore, the total number of observations may vary, causing the degrees of freedom to vary

TABLE 2.3

ANOVA model used for statistical analysis of gender interactions with space allowance or group size in blocks one and two only[1]

Variable	df	
Block	1	Compared to Error Term 1
Group Size (GS)	1	Compared to Error Term 1
Space (Sp)	1	Compared to Error Term 1
GS*Sp	1	Compared to Error Term 1
Block (GS*Sp)	3	Error Term 1
Gender	1	Compared to Default Error Term
GS*Gender	1	Compared to Default Error Term
Sp*Gender	1	Compared to Default Error Term
GS*Sp*Gender	1	Compared to Default Error Term
Residual Error	4	Default Error Term

[1]model used for analysis of initial and final body weights, daily gain, injury scores, and carcass data

TABLE 2.4

Basic ANOVA model used for data analyzed by week[1,2,3,4]

Variable	df	
Block	7	Compared to Error Term 1
Group Size (GS)	1	Compared to Error Term 1
Space (Sp)	1	Compared to Error Term 1
GS*Sp	1	Compared to Error Term 1
Block (GS*Sp)	21	Error Term 1
Week (wk)	7	Compared to Error Term 2
GS*wk	7	Compared to Error Term 2
Sp*wk	7	Compared to Error Term 2
GS*Sp*wk	7	Compared to Error Term 2
Block(GS*Sp*wk)	255	Error Term 2

[1]The basic model reflects an analysis that involved 8 blocks and 8 weeks. The number of blocks and weeks varied according to variables analyzed.

[2]The number of blocks varied for injury score analysis (7 blocks), postural behaviour observations and salivary cortisol concentrations (6 blocks)

[3]The number of weeks varied for daily gain and feed efficiency analysis (6 weeks), injury scores (5 weeks), postural behaviour observations and salivary cortisol concentrations (4 weeks)

[4]The degrees of freedom varied when blocks or weeks varied

represented in Table 2.2. Upon examination of raw daily feed intake data, it was recognized that certain data were erroneous because of dump scale or feed system malfunctions. So, when data deviated 20 % from the mean, or if obvious errors in the data could be seen, the erroneous data was removed.

A further analysis was conducted for daily gain data only. For each week, the score for each small crowded or large crowded treatment was expressed as a proportion of the corresponding uncrowded treatment (i.e. average daily gain of the large crowded treatment versus average daily gain of the large uncrowded treatment). A *k* value based on final average body weight for each week was calculated for each treatment as well. The calculation corrects for weekly changes in measures due to environmental conditions and age of pig.

The crowded:uncrowded average daily gain ratio was plotted against the *k* value for that interval and, within group size, analyzed using the NONLIN procedure in SAS to yield the break point and slope of the line below the break point. The break point represents the instant at which average daily gain within the pen begins to decrease. Prior to this point, the slope will be zero.

2.2.6.3 Behavioural time budgets

2.2.6.3.1 Feeding behaviour

Each pig's average meal duration (minutes), total meal duration (minutes), number of meals, and latency between meals (minutes) were analyzed for overall treatment differences, treatment differences occurring between each observation period, and treatment differences occurring within each observation period. The mean of each variable was calculated for each focal pig in each observation period. Means data analyzed was taken from blocks three through eight only, as pigs in blocks one and two were not videotaped.

There were three to four observations carried out per block. Since videotaping events were staggered between simultaneously running blocks, consecutive weeks from each block pair were combined to create one 'observation period' (see Tables A.2 and

A.3). For example, observation period one was week two in blocks 5, 6, and 8 and week three in blocks 3, 4, and 7. Overall treatment differences were analyzed using the MIXED procedure in SAS. Differences between observation periods, which were representative of differences among pig age and weight categories, were also analyzed using the MIXED procedure. The ANOVA model used was similar to that shown in Table 2.4. Differences between treatments occurring within each observation period were analyzed using the general linear model, and used an ANOVA model similar to that shown in Table 2.2.

Since none of the feeder usage variables were normally distributed, each had to be transformed. Logarithm (base 10) values were used for mean meal durations and mean latency scores, while square root values were used for the number of meals eaten and the total duration of time spent eating.

2.2.6.3.2 Postural behaviour

Postural behaviours were recorded during blocks three through eight only, and were observed three times per block (see Tables A.2 and A.3). Postural behaviours within a treatment were tallied and expressed as a percentage of time for each 24-hour observation period. Data were analyzed for differences between each observation period, which were representative of differences among pig age and weight categories, using the ANOVA model in Table 2.4 and the MIXED procedure in SAS. The data were also analyzed to determine if there were differences among the treatments within each week. The analysis employed an ANOVA model similar to that shown in Table 2.2, and statistical analysis was carried out using the general linear model.

In trying to determine a diurnal effect, observations had been carried out in three-hour segments throughout the 24-hour observation period. Postural behaviours within each segment (time period) were tallied and expressed as a percentage of time for individual treatments.

Raw time period data for standing, sitting, and lying lateral postures were not normally distributed. Standing and sitting data sets were transformed into square root values while lateral lying data were transformed into arcsine values. Eating and ventral lying postures were normally distributed and did not require transformation. Time period data were analyzed using the MIXED procedure, and used the ANOVA model shown in Table 2.5.

2.2.6.4 Injury scoring

Injury scores were calculated for both barrows and gilts at the beginning and end of the test period in blocks one and two only. Initial tail bite and lameness scores, as well as final flank bite scores, were not normally distributed. Therefore, those particular scores were transformed into square root values. All injuries were then assessed for differences among barrows and gilts using the general linear model in SAS.

Injury scores were averaged by treatment for each week that the pigs were scored. To make statistical analysis easier, scoring periods were used in the analysis rather than individual weeks. For example, the first set of injury scores taken from each block were labeled as the initial scoring period. The second set of injury scores taken was labeled as the second scoring period, and so on. Block seven was not included in the injury scoring analysis because the mean body weight of the pigs from each injury scoring week was not similar to the corresponding week in any other block. Injury scoring periods are shown in Table A.2. Body weights corresponding to each scoring period are shown in Table A.3.

Since the mean injury score values were not normally distributed, each was transformed into a square root value. Overall injury score differences and differences in scores at each scoring period were generated using the MIXED procedure in SAS, using the scoring period variable as a sub-plot. The ANOVA model employed is shown in Table 2.4.

Treatment differences within each scoring period were also analyzed. The analysis for within scoring period differences used the general linear model in SAS. The ANOVA model is shown in Table 2.2.

TABLE 2.5

ANOVA model used for postural behaviour data analyzed for diurnal effects[1,2,3]

Variable	df	
Block	5	Compared to Error Term 1
Group Size (GS)	1	Compared to Error Term 1
Space (Sp)	1	Compared to Error Term 1
GS*Sp	1	Compared to Error Term 1
Block (GS*Sp)	15	Error Term 1
Time Period (TP)	7	Compared to Error Term 2
GS*TP	7	Compared to Error Term 2
Sp*TP	7	Compared to Error Term 2
GS*Sp*TP	7	Compared to Error Term 2
Block (GS*Sp*TP)	140	Error Term 2

[1]only 6 blocks were used in analysis of postural behaviour data

[2]only 3 weeks (observation periods) worth of data were collected and used in data analysis; weeks were averaged

[3]only 8 of 9 time periods (representing 24 hours) were used in data analysis because the first time period (3 hours) was considered a habituation period

2.2.6.5 Animal morbidity

Animals requiring medication were segmented into two classifications: 'lame' or 'other'. Animals classified as 'other' may have been given treatment for arthritis, coughing, open or infected wounds, diarrhea, presence of a rash, or general unthriftiness. The number of animals in each classification was analyzed using the GENMOD procedure. The total number of animals given treatment over the duration of the study, regardless of classification, was also analyzed using the GENMOD procedure.

Animals that had to be removed from the study were segmented into three classifications: 'lame', 'tail bite', or 'other'. The 'other' category included animals that had died, animals with severe wounds, animals with an ailment that was resistant to antibiotic treatment, animals with a large abdominal hernia, those with a rectal prolapse, or weak, poor-doing pigs. The number of animals in each classification was analyzed using the GENMOD procedure. The total number of animals removed throughout the entire study, regardless of classification, was also analyzed using the GENMOD procedure. For all analyses, the ANOVA model used was that shown in Table 2.2.

2.2.6.6 Salivary cortisol concentrations

The cortisol concentrations of all of the samples were statistically analyzed to determine whether there were overall treatment differences and whether there were differences between sampling weeks using the ANOVA model shown in Table 2.4. Salivary cortisol concentrations within the first sampling week were analyzed for differences between samples taken when the technician had been in the pen sampling for less than five minutes versus more than five minutes. This was carried out to determine whether there was an effect of the amount of time that was spent sampling on the concentration of cortisol, and thus, stress. Only the first sampling week could be tested since individual samples were only available from that week.

Salivary cortisol concentration data were not normally distributed and were not able to be transformed into normally distributed values. Therefore, group size, space allowance, and interaction effects on salivary cortisol concentrations were tested for significance using the Friedman two-way analysis of variance; a non-parametric test (Lehner, 1979). Calculations were carried out manually.

2.2.6.7 Post mortem adrenal gland analysis

Adrenal gland data taken from the left gland were statistically analyzed using the general linear model in SAS. The effects of treatment on the cortex area, medulla area, cortex:medulla ratio, total gland area, cortex:total area ratio, left adrenal gland weight, live off-test body weight, and adrenal weight:body weight ratio were examined. The adrenal gland weight data were not normally distributed. Therefore, gland weight values were transformed into cosine values. The ANOVA model used for this procedure is shown in Table 2.2. Since adrenal glands were only collected from randomly selected focal pigs in blocks three through eight, only these six blocks were used in statistical analyses.

2.2.6.8 Carcass measurements

Data collected for statistical purposes included pig carcass value index, percent lean yield, fat depth, and lean depth. Barrow and gilt data from blocks one and two were analyzed to determine whether there were production differences between the genders, or if there were interaction effects of gender and space allowance or group size. Data were analyzed using the general linear model in SAS and the ANOVA model shown in Table 2.3. Neither percent lean yield nor lean depth were normally distributed in blocks one or two. Therefore, both data sets were transformed into tangent values. Carcass value index and fat depth were determined to be normally distributed by SAS and thus, did not require transformation.

In further analysis, data from both barrows and gilts in blocks one and two were averaged within their respective treatments. No data from blocks seven or eight was used due to a change in market weight regulations during that time period. Therefore, only data from blocks one through six were compared. The data were analyzed using the MIXED procedure in SAS and the ANOVA model shown in Table 2.2.

2.3 Results

Initial body weights and the corresponding coefficient of variation as well as initial injury scores (taken on day zero) are shown in Table 2.6. All results in tables and figures have been reported as least squares means.

2.3.1 Gender

While effects of gender were evident for some variables measured, other traits showed no effects. Barrows gained more than gilts ($P = 0.02$), but initial and final body weights, and their corresponding coefficients of variation did not differ significantly between the genders (Table 2.7). Barrows had greater fat thicknesses than gilts ($P = 0.002$; Table 2.7), but gilts had a higher carcass value index than barrows ($P = 0.01$; Table 2.7). Injury scores were not affected by the pigs' gender. Furthermore, there were no gender x space allowance, or gender x group size interaction effects for any of the variables measured, indicating that neither gender was affected more by restricted space or large group size.

2.3.2 Productivity

Space allowance affected overall daily gain and feed efficiency, but did not significantly affect the daily feed intake of pigs. Crowded pigs gained less ($P = 0.02$) and were less efficient ($P = 0.002$) than uncrowded pigs (Table 2.8). Final body weights were lower among crowded pigs than uncrowded pigs as well, providing further evidence that space allowance had an effect on overall gains ($P = 0.002$; Table 2.8).

TABLE 2.6

Description of the treatment set-up and the initial body weights, coefficients of variation, and injury scores as grow-finish pigs began the test phase of the study

	Treatments[a]					*P*-value		
Item	SUC	SC	LUC	LC	SEM	Space	Group Size	SP x GS
# pigs/experimental unit	36	36	108	108	—	—	—	—
# experimental units/block[b]	1	1	1	1	—	—	—	—
space allowance (m^2/pig)	0.78	0.52	0.78	0.52	—	—	—	—
initial BW[c] (kg)	38.01	38.02	36.55	36.97	0.37	0.57	0.003	0.58
$CV_{initial\ BW}$	16.73	16.65	15.73	16.81	0.84	0.56	0.62	0.50
initial injury scores[cd]								
lameness	0.013	0.024	0.019	0.006	0.014	0.38	0.76	0.40
flank bites	0.016	0.000	0.027	0.010	0.010	0.13	0.10	0.77
tail bites	0.0214	0.0043	0.0114	0.0171	0.0083	0.19	0.10	0.14
leg lesions	0.101	0.049	0.116	0.073	0.035	0.15	0.06	0.10
% pigs with leg bursa	25.8	20.6	27.5	21.4	4.9	0.65	0.08	0.78

[a] SUC: small uncrowded, SC: small crowded, LUC: large uncrowded, LC: large crowded

[b] two adjacent small pens (18 pigs/pen) were equivalent to one experimental unit

[c] taken after a habituation period of three days for blocks 1, 2, 6, and 8, four days for blocks 3, 4, and 5, and ten days for block 7

[d] means represent the average of values from all 8 blocks; injury scores ranged from no injury (score 0) to the highest severity of 3 (lameness), 4 (tail bites), or 5 (flank bites and leg lesions); *P*-values are derived from the analysis of the square root transformation of the raw data (except for leg bursa)

TABLE 2.7

The effects of gender of grow-finish pigs on variables assessed in blocks one and two[1,2]

Item	Gender: Barrow	Gender: Gilt	SEM	*P* -value
# of experimental units	8	8	—	—
initial BW[a] (kg)	37.33	37.95	0.52	0.44
$CV_{initial\ BW}$	13.16	12.20	0.73	0.40
final BW (kg)	89.49	87.54	0.84	0.17
$CV_{final\ BW}$	9.50	9.29	0.74	0.85
overall ADG (kg/day)	1.0644	1.0124	0.0094	0.02
carcass data				
carcass value index	111.95	114.01	0.32	0.01
percent lean yield[b]	59.61	60.85	0.15	0.06
loin fat depth (mm)	20.57	18.02	0.25	0.002
loin lean depth (mm)[b]	60.1	63.1	1.3	0.23
initial injury scores[a]				
lameness[c]	0.0138	0.0000	0.0097	0.37
flank bites	0.045	0.000	0.021	0.21
tail bites[c]	0.0000	0.0050	0.0025	0.23
leg lesions	0.035	0.149	0.066	0.29
% with leg bursa	18.1	12.7	3.3	0.32
final injury scores				
lameness	0.044	0.013	0.016	0.25
flank bites[c]	0.0738	0.0838	0.0035	0.37
tail bites	0.0438	0.0238	0.0090	0.19
leg lesions	0.040	0.048	0.027	0.86
% with leg bursa	4.9	8.3	1.4	0.16

[1] only blocks 1 and 2 housed both barrows and gilts, so data presented is representative of blocks 1 and 2 only (4 units per block)

[2] means represent the average of values from blocks 1 and 2; injury scores ranged from no injury (score 0) to the highest severity of 3 (lameness), 4 (tail bites), or 5 (flank bites and leg lesions)

[a] taken after a habituation period of 3 days

[bc] *P* -values are derived from the analysis of the [b]tangent transformation or [c]square root transformation of the raw data

TABLE 2.8

Body weights, corresponding CV's, daily gain, daily feed intake, and feed efficiency of grow-finish pigs housed at different group sizes and space allowances

	Space Allowance[a]		Group Size[a]			*P* -value	
Item	UC	C	S	L	SEM	Space	Group Size
# experimental units	16	16	16	16	—	—	—
initial BW[b] (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	< .0001
$CV_{final\ BW}$	11.27	11.26	11.43	11.10	0.36	> 0.95	0.52
overall ADG[c]	1.077	1.032	1.073	1.035	0.015	0.02	0.04
week 2	1.053	1.054	1.083	1.024	0.013	0.93	0.01
week 3	1.039	1.031	1.046	1.025	0.021	0.70	0.32
week 4	1.121	1.053	1.109	1.064	0.046	0.02	0.10
week 5	1.088	1.015	1.078	1.025	0.031	0.09	0.21
week 6	1.085	1.077	1.065	1.097	0.044	0.89	0.56
week 7	1.067	0.962	1.048	0.981	0.035	0.03	0.14
overall ADFI[c]	2.774	2.834	2.824	2.783	0.049	0.34	0.51
week 2	2.393	2.526	2.484	2.435	0.073	0.12	0.57
week 3	2.477	2.731	2.616	2.602	0.072	0.009	0.88
week 4	2.709	2.833	2.788	2.754	0.055	0.11	0.65
week 5	2.973	2.943	2.997	2.919	0.074	0.76	0.44
week 6	3.033	3.016	2.993	3.057	0.066	0.83	0.43
week 7	3.108	3.164	3.097	3.175	0.083	0.61	0.49
overall FE[c]	0.3958	0.3697	0.3945	0.3710	0.0055	0.002	0.005
week 2	0.444	0.413	0.441	0.416	0.012	0.09	0.16
week 3	0.424	0.383	0.411	0.395	0.013	0.03	0.36
week 4	0.415	0.381	0.410	0.386	0.015	0.02	0.08
week 5	0.379	0.369	0.388	0.360	0.013	0.49	0.06
week 6	0.359	0.361	0.360	0.360	0.016	0.93	> 0.95
week 7	0.356	0.316	0.360	0.313	0.011	0.008	0.004

[a] UC: uncrowded, C: crowded, S: small, L: large

[b] taken after a habituation period of 3 days for blocks 1, 2, 6, and 8, four days for blocks 3, 4, and 5, and 10 days for block 7

[c] ADG: average daily gain (kg/day), ADFI: average daily feed intake (kg/day), FE: feed efficiency (kg gained per kg feed consumed)

By looking at the breakdown of the performance parameters each week, it can be seen that average daily gain was most affected by space allowance when the pigs were most crowded. During that final week, the gains of pigs in the uncrowded space allowance treatment exceeded those in the crowded treatment by 9.8 % ($P = 0.03$; Table 2.8). Feed efficiency was also affected to the greatest extent during the final week at which point the difference between the crowded and uncrowded treatments was 11.2 % ($P = 0.008$; Table 2.8).

Group size did not have as drastic an effect on productivity as did space allowance, although significant effects were also seen. Overall, pigs in the small group gained more than those in large groups ($P = 0.04$; Table 2.8). Resulting final body weights, which differed by 3.0 %, support this finding ($P < 0.0001$; Table 2.8). Overall, pigs in small groups also had higher feed efficiencies than large group pigs ($P = 0.005$; Table 2.8).

The large group pigs had a 3.3 % lower initial body weight than the small group pigs ($P = 0.003$; Table 2.8). Daily gains were most affected in the first week of the study, at which point the pigs in the small group had daily gains exceeding that of pigs in the large group by 5.4 % ($P = 0.01$; Table 2.8).

Feed efficiency was most affected by group size during the final week, at which point pigs housed in small groups were 13 % more efficient in utilizing the feed they consumed than those housed in the large groups ($P = 0.004$; Table 2.8). There were no significant interactions of group size and space allowance for daily gains, daily feed intake, or feed efficiency (Table B.1).

The broken line analysis graphs in Figure 2.2 plot the daily gain of the crowded pigs against that of the uncrowded pigs in order to show how both (a) small and (b) large group housed pigs respond to space restriction. Examination of the graphs shows small groups experiencing reduced gains at a critical k value of 0.035, which is near the predicted value of $k = 0.034$. However, the large group housed pigs are showing signs of reduced gains at $k = 0.042$. Even though pigs in the large group were experiencing reduced gains earlier on, the rate of decline was more gradual over time than in the small groups. Gains were depressed by 0.2 % for every 1 % reduction in space below the critical value ($k = 0.042$) in the large group, while gains in the small group were

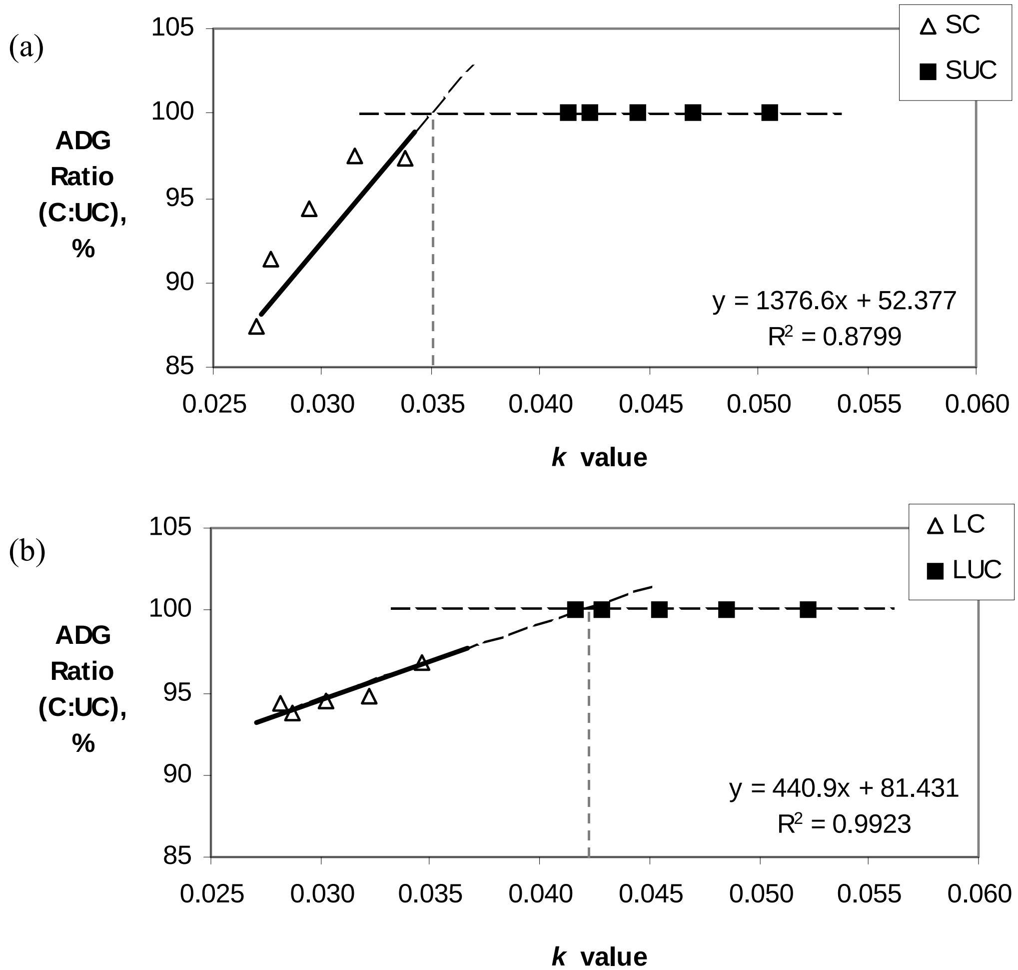

FIGURE 2.2 The broken line analysis showing the ratio of daily gain in the crowded treatment to daily gain in the uncrowded treatment for both (a) small and (b) large groups of grower-finisher pigs over time. The solid line is the trendline to which the crowded treatment R^2 values apply. The dark-coloured dashed lines indicate the intersection of the crowded and uncrowded trendlines, and the light-coloured dashed line indicates the *k* value at which this intersection occurs ($k = 0.035$ for small groups and $k = 0.042$ for large groups). Each point on the graphs represents an average of the gains from three consecutive weeks (i.e. weeks 2, 3, and 4, then weeks 3, 4, and 5, and so on). The corresponding *k* value is derived from the average of the *k* values from those same three weeks.

depressed by 0.5 % for every 1 % reduction in space below the critical value (*k* = 0.035). The net effect of crowding in the large and small groups on gains at the end of the trial was similar (0.963 vs. 0.962 for large crowded and small crowded groups respectively, SEM = 0.046, *P* = 0.13).

2.3.3 Behavioural time budgets

2.3.3.1 Feeding behaviour

Space allowance did not affect the overall number of meals a pig consumed per day (i.e. per observation period). Space did not affect overall mean meal duration, total meal duration, or mean latency to the next meal. However, space allowance did affect the number of meals eaten per pig during the fourth observation period. At that time, uncrowded pigs were eating more meals per day than crowded pigs (*P* = 0.01; Table 2.9). The total meal duration was higher among uncrowded pigs during the observation period as well (*P* = 0.02; Table 2.9). Latencies between meals were shorter for uncrowded pigs than for crowded pigs during the fourth observation period (*P* = 0.004; Table 2.9).

Group size had many effects on the feeding pattern of pigs. The overall number of meals was greater for pigs in small groups than in large groups (*P* = 0.002), and remained that way through the first, third, and fourth observation periods (*P* = 0.02, *P* = 0.03, *P* = 0.005, respectively; Figure 2.3 (a)). Mean meal durations were lower among small group housed pigs overall (*P* = 0.0003), and during the first, second, and fourth observation periods (*P* = 0.004, *P* = 0.005, *P* = 0.003, respectively; Figure 2.3 (b)). Total meal duration was not affected by group size (Table 2.9), but the mean latency to a pig's next meal was. Overall, mean latencies were lower among small group housed pigs than large group housed pigs (*P* = 0.001; Figure 2.3 (c)). The mean latencies were also lower among small group housed pigs during the second, third, and fourth observation periods (*P* = 0.03, *P* = 0.06, *P* = 0.004, respectively; Figure 2.3 (c)).

TABLE 2.9

Effects of space allowance, group size, and the space allowance x group size interaction of the feeding patterns of grow-finish pigs

	Space Allowance[a]		Group Size[a]			Interactions[b]					*P* -value		
Item	UC	C	S	L	SEM	SUC	SC	LUC	LC	SEM	Space	Group Size	SP x GS
# experimental units	12	12	12	12	—	6	6	6	6	—	—	—	—
Mean # of meals (24-hours)[ce]	10.97	9.87	11.70	9.15	0.71	12.44	10.96	9.50	8.79	0.86	0.33	0.002	0.67
First observation[d]	—	—	16.3	10.4	1.5	—	—	—	—	—	—	0.02	—
Second observation	10.8	10.6	12.2	9.3	1.5	12.2	12.1	9.4	9.2	1.9	> 0.95	0.10	0.88
Third observation	11.38	10.38	11.79	9.96	0.83	12.38	11.21	10.37	9.54	0.97	0.16	0.03	0.83
Fourth observation	10.94	8.71	11.24	8.40	0.79	12.90	9.59	8.98	7.83	0.94	0.01	0.005	0.23
Mean Meal Duration (min)[cf]	6.53	6.08	5.26	7.35	0.54	4.81[z]	5.71[yz]	8.25[x]	6.45[y]	0.66	0.68	0.0003	0.01
First observation[d]	—	—	4.59	8.31	0.62	—	—	—	—	—	—	0.004	—
Second observation	6.62	5.99	5.07	7.54	0.48	5.15	4.98	8.08	7.01	0.59	0.43	0.005	0.57
Third observation	6.10	6.07	5.62	6.55	0.68	4.83[z]	6.42[xy]	7.38[wx]	5.72[wyz]	0.87	0.94	0.21	0.04
Fourth observation	6.80	6.24	4.96	8.08	0.69	4.44	5.47	9.15	7.01	0.96	0.89	0.003	0.08
Total Duration (min/24-hours)[ce]	60.9	55.2	55.7	60.4	3.6	54.8[y]	56.5[y]	67.0[x]	53.9[y]	4.2	0.82	0.37	0.03
First observation[d]	—	—	57.2	69.6	4.1	—	—	—	—	—	—	0.52	—
Second observation	62.6	61.4	57.3	66.7	7.4	54.3	60.3	70.8	62.6	7.9	0.75	0.13	0.14
Third observation	60.5	55.8	59.8	56.5	4.0	57.1	62.5	63.9	49.0	5.5	0.29	0.51	0.06
Fourth observation	59.7	49.3	51.0	58.0	3.3	53.8	48.2	65.6	50.4	4.3	0.02	0.24	0.23
Mean latency to next meal (min)[cf]	133.2	145.9	120.1	159.0	8.6	115	125	151	167	10	0.36	0.001	0.64
First observation[d]	—	—	107	142	21	—	—	—	—	—	—	0.34	—
Second observation	131	122	114	140	12	126	102	137	142	16	> 0.95	0.03	0.71
Third observation	129.3	129.4	116.4	142.2	9.4	112	121	147	138	11	0.87	0.06	0.42
Fourth observation	142	187	130	198	14	110	151	174	222	18	0.01	0.004	0.44

[a] UC: uncrowded, C: crowded, S: small group, L: large group

[b] SUC: small uncrowded treatment, SC: small crowded treatment, LUC: large crowded treatment, LC: large crowded treatment

[c] Overall values included analysis of second, third, and fourth periods only; blocks 1 & 2 were not videotaped so were not included in the analysis

[d] During the first observation period, video data for the large crowded group was lost, so only uncrowded group size comparisons could be made

[e] *P* -values are derived from analysis of the sqare root transformation of the raw data for number of meals and total meal duration

[f] *P* -values are derived from analysis of the logarithm (base 10) transformation of the raw data for mean meal duration & mean latency to next meal

[wxyz] Means within the same row sharing a common superscript or having no superscript do not differ significantly ($P > 0.05$)

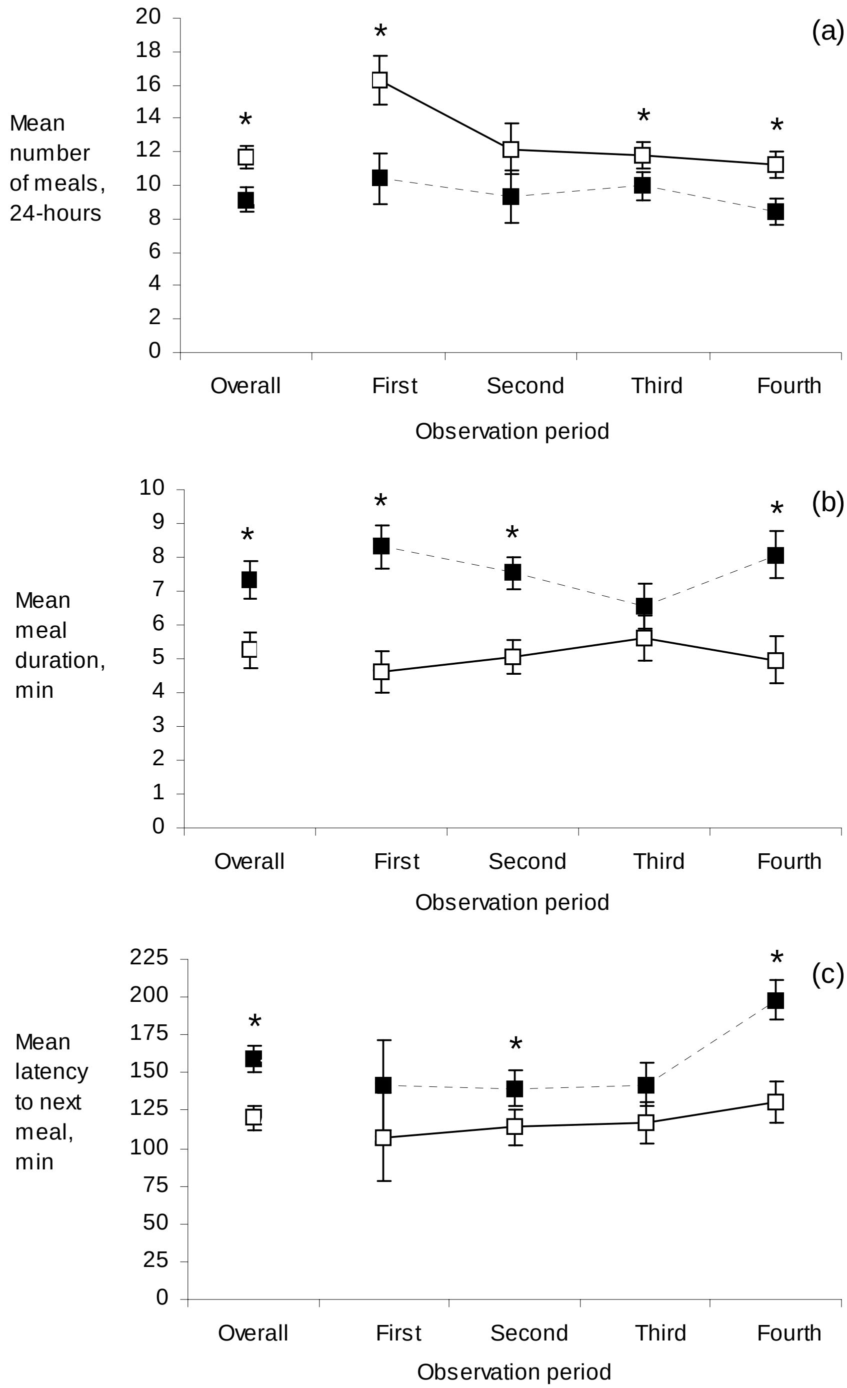

FIGURE 2.3 The (a) mean number of meals, (b) mean meal duration, and (c) mean latency to the next meal of grow-finish pigs housed in large (■) or small (□) groups in blocks three through eight. Data was taken from each block at two-week intervals. First = 43 kg BW; Second = 65 kg BW; Third = 80 kg BW; Fourth = 95 kg BW. Error bars represent the mean ± SEM. Symbols indicate the comparison of 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 Log_{10} transformation of the raw data.

Interactions of group size and space were seen for some of the variables assessed. The large uncrowded group had the longest overall mean meal duration (*P* = 0.01), which differed from all of the other treatment groups (Table 2.9). During the third observation period, the large uncrowded group again had the longest mean meal duration (*P* = 0.04), but it only differed from that of the small uncrowded group (Table 2.9). Overall, total meal durations also differed among the treatments, with the large uncrowded group spending the most time eating during a 24-hour period (*P* = 0.03; Table 2.9). The other treatments differed from the large uncrowded treatment, but did not differ from each other (Table 2.9). The number of meals per pig per day and the mean latency to the next meal did not differ among the treatments at any point during the study.

2.3.3.2 Postural behaviour

When space allowance was restricted, overall eating behaviour was altered. Pigs that were crowded spent less time eating than pigs that were not crowded (*P* = 0.003; Table 2.10). Restricting the amount of space provided to the pigs did not affect the proportion of time the pigs spent sitting, standing, lying ventrally or lying laterally.

The proportion of time pigs spent sitting, lying ventrally and lying laterally was affected by the size of group in which pigs were housed. Pigs housed in large groups spent less time sitting than pigs housed in small groups (*P* = 0.003; Table 2.10), they spent less time lying ventrally than the pigs housed in small groups (*P* = 0.002; Table 2.10), and they spent more time lying laterally than the pigs housed in small groups (*P* = 0.01; Table 2.10).

Interactions of space allowance and group size were only evident for eating and sitting behaviours. The pigs housed in small uncrowded groups spent more time eating than any other treatment group. The pigs housed in small crowded groups spent less time eating than both of the large groups. Eating behaviour did not differ between the two large groups of pigs. Pigs housed in the small uncrowded group sat more than pigs in either of the large groups. The proportion of time spent sitting by pigs housed in

TABLE 2.10

Proportion of time spent by grower-finisher pigs eating, standing, sitting, lying ventrally, or lying laterally over the entire trial

	Space Allowance[a]		Group Size[a]		Interactions[b]					*P* -value		
Item	UC	C	S	L	SUC	SC	LUC	LC	SEM	Space	Group Size	SP x GS
# experimental units	12	12	12	12	6	6	6	6	—	—	—	—
eating	6.04	5.38	5.69	5.73	6.33[x]	5.04[z]	5.75[y]	5.71[y]	0.27	0.003	0.83	0.005
standing	8.27	7.63	7.52	8.37	7.42	7.63	9.13	7.63	0.56	0.16	0.07	0.07
sitting	2.90	2.85	3.27	2.48	3.54[x]	3.00[xy]	2.25[z]	2.71[yz]	0.23	0.85	0.003	0.04
lying ventrally	22.50	22.08	23.52	21.06	23.50	23.54	21.50	20.63	0.89	0.54	0.002	0.50
lying laterally	60.3	62.0	59.9	62.4	59.2	60.5	61.3	63.4	1.4	0.07	0.01	0.69

[a] UC: uncrowded, C: crowded, S: small, L: large

[b] SUC: small uncrowded treatment, SC: small crowded treatment, LUC: large crowded treatment, LC: large crowded treatment

[xyz] Means within the same row sharing a common superscript or having no superscript do not differ significantly ($P > 0.05$); Means represent a percentage of time in a 24-hour day

small crowded groups exceeded that of pigs housed in large uncrowded groups. There were no differences in sitting behaviour between either of the two small groups of pigs or between either of the two large groups of pigs. Results are shown in Table 2.10.

As the pigs grew, the overall proportion of time they spent eating, standing, and lying ventrally decreased. The proportion of time spent eating decreased from 6.89 % during the first observation to 4.95 % during the last (fourth) observation (SEM = 0.29, $P < 0.0001$). The proportion of time spent standing decreased from 11.10 % during the first observation to 6.07 % in the last observation (SEM = 0.57, $P < 0.0001$). The 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 (SEM = 1.0, $P = 0.0001$). The overall proportion of time the pigs spent lying laterally increased significantly over time, from 54.9 % in the first observation period to 65.7 % in the last observation period (SEM = 1.4, $P < 0.0001$). Sitting behaviour decreased marginally over time, but the level of change was not significant ($P > 0.05$).

By breaking the live observations into periods, differences within each period could be seen. The amount of space provided affected the amount of time the pigs were spending lying laterally during the second observation period ($P = 0.01$; Table B.2). Group size affected the proportion of time the pigs were spending sitting during the second period ($P = 0.05$), lying ventrally during the initial ($P = 0.005$), second ($P = 0.01$) and third periods ($P = 0.03$), and the amount of time the pigs spent lying laterally during the initial ($P = 0.03$) and final periods ($P = 0.04$). These results are shown in Table B.2.

There are particular times of day that pigs prefer to eat or rest. Pigs spent the majority of the time eating between 0700 and 1800 hours, with the highest proportion of time spent eating occurring from 1600 to 1800 hours ($P < 0.0001$; Figure 2.4 (a)). Eating behaviour decreased in the late evening and early morning, from 1900 to 2400 and from 0100 to 0600.

Standing behaviour peaked during the mid-afternoon hours of 1300 to 1500 ($P < 0.0001$; Figure 2.4 (b)). Pigs spent somewhat less time standing from 0700 to 1200 hours, but the least time spent standing occurred in the late evening and early morning (from 1900 to 2400 and from 0100 to 0600).

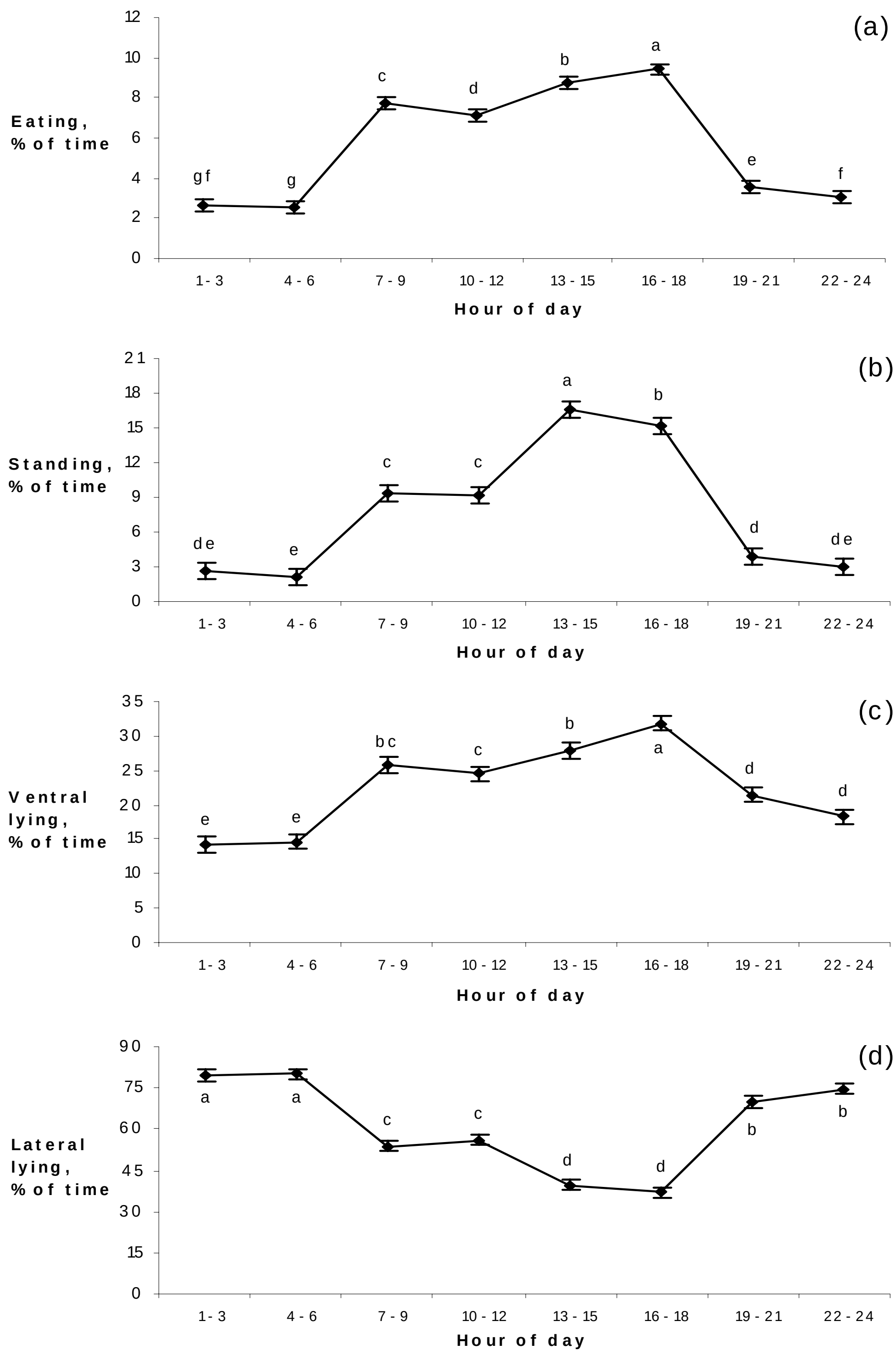

FIGURE 2.4 The overall proportion of time that grower-finisher pigs in blocks three through eight spent (a) eating, (b) standing, (c) lying ventrally or (d) lying laterally at different time periods throughout a 24-hour day. Means sharing a common letter do not differ significantly ($P > 0.05$). Error bars represent the mean ± SEM; *P*-values were derived from the analysis of the square root transformation of the raw data for (a) eating and (b) standing while *P*-values for (c) ventral lying and (d) lateral lying were derived from the analysis of the arcsine transformation of the raw data.

Sitting behaviour followed a very similar pattern to standing behaviour, although the percentage of time spent sitting during any time period was less than that spent standing in the corresponding period. Since standing and sitting behaviour patterns were very similar, only standing behaviour was presented in Figure 2.4.

Pigs spent the most time lying ventrally from 0700 to 1800 hours, and the behaviour peaked between 1600 and 1800 hours ($P < 0.0001$; Figure 2.4 (c)). 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 behaviours. The posture was assumed most frequently from 1900 to 0300 hours, peaking between 0100 to 0300 ($P < 0.0001$; Figure 2.4 (d)). From 1300 to 1800 hours, lateral lying occurred the least. Intermediate values for lateral lying behaviour fell between 0700 and 1200 hours.

Space allowance and group size also had significant effects on certain behaviours within a particular time period (time of day). Uncrowded pigs spent more time standing from 1000 to 1200 hours and from 1300 to 1500 hours than crowded pigs ($P = 0.009$; Figure 2.5 (b)). Crowded pigs spent more time lying laterally from 0100 to 0300 hours and from 1300 to 1500 hours than uncrowded pigs ($P = 0.008$; Figure 2.5 (c)). Pigs housed in small groups spent a greater proportion of their time sitting than pigs housed in large groups during all periods observed between 0700 and 1800 hours ($P = 0.003$; Figure 2.5 (a)). There were no group size x space allowance interactions for any behaviour within any of the time periods observed (Table B.3).

2.3.4 Injury scoring

Injury scores were not affected by space allowance. However, group size was found to influence lameness and leg lesion scores. Pigs housed in large groups experienced more lameness than pigs housed in small groups, and had a higher overall

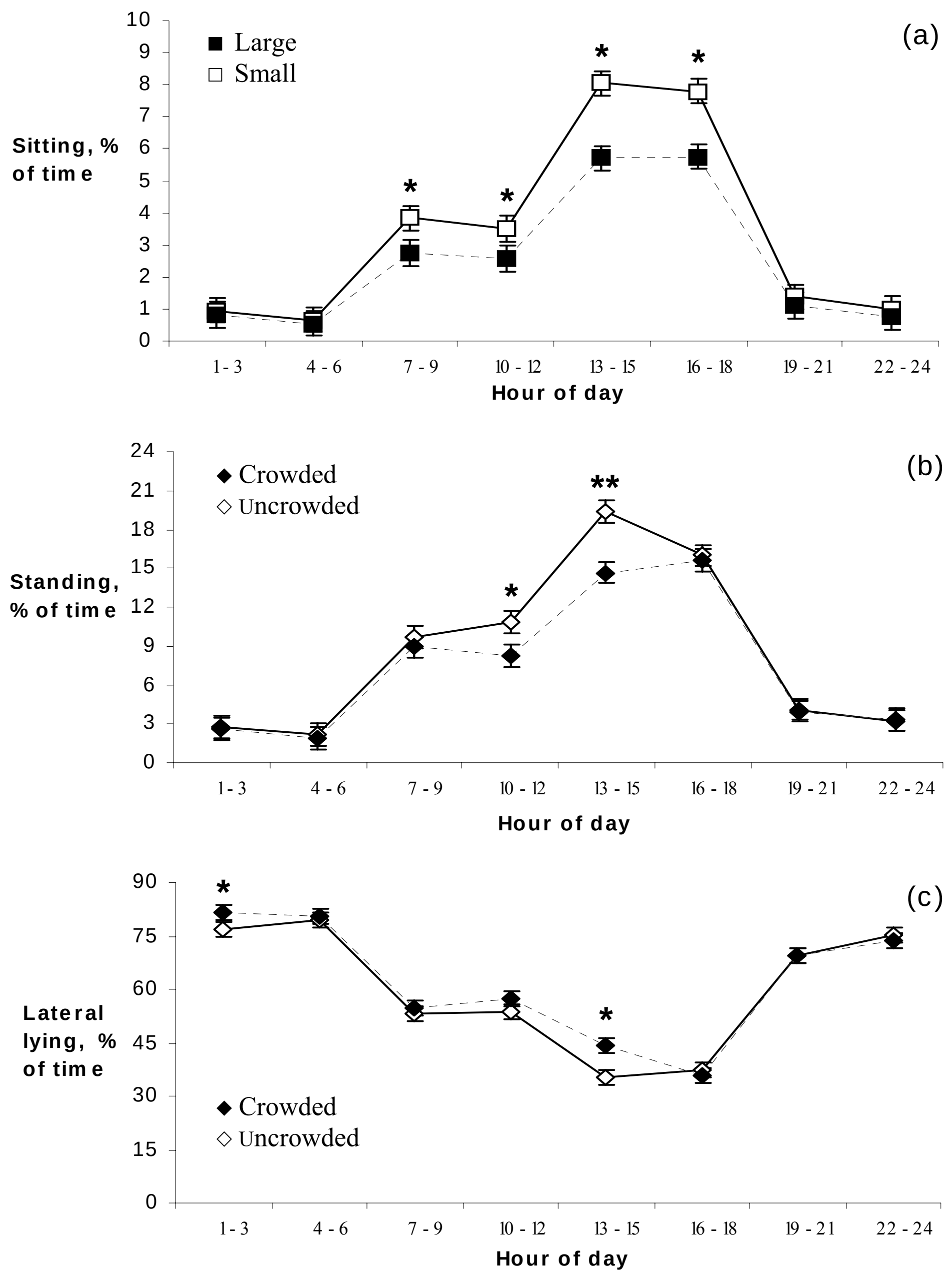

FIGURE 2.5 The proportion of time that grower-finisher pigs in small or large groups, or at crowded or uncrowded space allowances spent (a) sitting, (b) standing or (c) lying laterally within each observed time period in blocks three through eight. The figures represent an average of data taken from each block at two-week intervals. Error bars represent the mean ± SEM. Symbols indicate the comparison for differences between values (* P < 0.05; ** P < 0.0001); P-values were derived from the analysis of the square root transformation of the raw data for (a) sitting and (b) standing, while P-values for (c) lateral lying were derived from the arcsine transformation of the raw data.

incidence of leg lesions (*P* = 0.01 and *P* = 0.02, respectively; Table 2.11). There were also group size x space allowance interactions seen for lameness scores. Pigs housed in the large crowded groups had the highest scores, followed by pigs housed in small uncrowded groups, then pigs in large uncrowded groups (*P* = 0.04; Table 2.11).

When sub-dividing the injury scores into scoring periods, few differences between space allowance treatments were evident. Leg lesion scores were significantly higher among crowded pigs than among uncrowded pigs at the final scoring period only (*P* = 0.04; Table 2.12). There were no other effects of space allowance on type of injury at a particular scoring period.

Effects of group size on leg lesion scores were evident at the second scoring period, at which time pigs housed in large groups had a higher score than pigs housed in small groups (*P* = 0.005; Table 2.12). Pigs housed in large groups were also experiencing more lameness at the time of the second scoring period (*P* = 0.04) and the final scoring period (*P* = 0.01; Table 2.12). Furthermore, the proportion of pigs with leg bursa was affected by group size during the second scoring period. At that time, the presence of a leg bursa was evident among 32.1 % of pigs housed in large groups versus 29.9 % of pigs housed in small groups (*P* = 0.03; Table 2.12).

There were group size x space allowance interaction effects for lameness scores during the second and final scoring periods. Pigs housed in the large crowded groups had the highest scores for the second and final scoring periods, while pigs housed in the small crowded groups had the lowest scores (*P* = 0.05 and *P* = 0.04 for the second and final scoring periods, respectively; Table 2.13).

2.3.5 Animal morbidity

In block three, beginning in week seven (average body weight: 85 kg) there was an outbreak of Pityriasis Rosea (Pustular Psoriaform Dermatitis). Pigs that had the disease did not show visual signs of reduced performance, and welfare seemed to be unaffected.

TABLE 2.11

Effects of group size, space allowance, and their interaction on the injury scores of grow-finish pigs

	Space Allowance[a]		Group Size[a]			Interactions[a]					P-values		
Item	UC	C	S	L	SEM	SUC	SC	LUC	LC	SEM	Space	Group Size	SP x GS
# experimental units	16	16	16	16	—	8	8	8	8	—	—	—	—
Injury[b]													
Lameness	0.025	0.024	0.019	0.030	—	0.027	0.010	0.022	0.037	—	—	—	—
Lameness[c]	0.106	0.093	0.061	0.138	0.032	0.098[xy]	0.025[y]	0.114[x]	0.162[x]	0.037	0.65	0.01	0.04
Flank bites	0.034	0.044	0.036	0.041	0.014	0.028	0.044	0.039	0.043	0.020	> 0.95	0.27	> 0.95
Tail bites	0.038	0.047	0.054	0.031	0.017	0.048	0.061	0.029	0.032	0.019	0.69	0.41	0.84
Leg lesions	0.140	0.154	0.128	0.166	0.056	0.107	0.150	0.172	0.159	0.062	0.80	0.02	0.75
Leg bursa[d]	26.6	23.2	25.0	24.8	2.5	28.3	21.6	24.8	24.8	2.7	0.55	0.31	0.71

[a] UC: uncrowded, C: crowded, S: small, L: large, SUC: small uncrowded, SC: small crowded, LUC: large uncrowded, LC: large crowded

[b] Blocks one and two were only scored the day they began test and the day they ended the test phase. Pigs in other blocks were scored bi-weekly; means represent an average of the injury scores taken from all weeks in all eight blocks; injury scores ranged from no injury (score 0) to the highest severity of 3 (lameness), 4 (tail bites), or 5 (flank bites and leg lesions);

P-values derived from analysis of the square root transformation of raw data, with the exception of leg bursa *P*-values, which were derived from analysis of the sine transformation of the raw data

[c] Values are transformed data means

[d] Expressed as the percentage of pigs that have one or more bursa present on the olecranon joint

[xyz] Means within the same row sharing a common superscript or having no superscript do not differ significantly ($P > 0.05$)

TABLE 2.12

The effects of space allowance and group size on injury scores of grow-finish pigs when scoring was sub-divided into bi-weekly scoring periods[1]

	Space Allowance[a]		Group Size[a]			*P*-values[b]	
Item	UC	C	S	L	SEM	Space	Group Size
# experimental units	16	16	16	16	—	—	—
Lameness							
Initial scoring[c]	0.016	0.015	0.019	0.012	0.011	0.38	0.76
Second scoring	0.0093	0.0162	0.0052	0.0204	0.0084	0.54	0.04
Third scoring	0.0170	0.0230	0.0150	0.0250	0.0086	0.48	0.11
Fourth scoring	0.042	0.029	0.026	0.045	0.015	0.49	0.07
Final scoring	0.049	0.041	0.036	0.055	0.013	0.25	0.01
Flank Bites							
Initial scoring[c]	0.0214	0.0050	0.0079	0.0186	0.0072	0.13	0.10
Second scoring	0.0079	0.0040	0.0024	0.0039	0.0070	0.79	0.79
Third scoring	0.0140	0.0130	0.0170	0.0100	0.0099	0.76	0.92
Fourth scoring	0.029	0.082	0.053	0.058	0.031	0.33	0.36
Final scoring	0.094	0.134	0.106	0.121	0.036	0.66	0.30
Tail Bites							
Initial scoring[c]	0.0164	0.0107	0.0129	0.0143	0.0067	0.19	0.10
Second scoring	0.049	0.034	0.051	0.032	0.017	0.46	0.37
Third scoring	0.035	0.044	0.047	0.032	0.015	0.38	0.29
Fourth scoring	0.055	0.076	0.085	0.046	0.025	0.60	0.37
Final scoring	0.064	0.097	0.104	0.058	0.044	0.35	0.56
Leg Lesions							
Initial scoring[c]	0.109	0.061	0.075	0.094	0.032	0.15	0.06
Second scoring	0.064	0.049	0.032	0.081	0.024	0.46	0.005
Third scoring	0.144	0.134	0.125	0.153	0.061	0.85	0.33
Fourth scoring	0.240	0.251	0.207	0.284	0.077	0.94	0.14
Final scoring	0.27	0.41	0.34	0.35	0.14	0.04	0.37
Leg Bursa (% of pigs)							
Initial scoring[c]	26.7	21.0	23.2	24.5	3.5	0.65	0.08
Second scoring	30.7	31.3	29.9	32.1	6.1	0.72	0.03
Third scoring	32.0	27.6	31.9	27.8	3.4	0.51	> 0.95
Fourth scoring	27.0	23.1	24.9	25.2	3.6	0.45	0.16
Final scoring	16.4	13.0	14.9	14.5	3.6	0.82	0.91

[1] block 7 not included in analysis or data representation; blocks one and two included in initial and final scoring periods only

[a] UC: uncrowded, C: crowded, S: small, L: large

[b] *P*-values are derived from analysis of the square root transformation of the raw data, except for leg bursa *P*-values, which have been derived from analysis of the sine transformation of the raw data

[c] initial scoring was taken after a habituation period of three days for blocks 1, 2, 6, and 8, and four days for blocks 3, 4, and 5

TABLE 2.13

Group size x space allowance interaction effects for injury scores of grow-finish pigs when scoring was sub-divided into bi-weekly scoring periods[1]

	Interaction[a]					
Item	SUC	SC	LUC	LC	SEM	*P*-value[b]
# experimental units	8	8	8	8	—	—
Lameness						
Initial scoring[c]	0.013	0.024	0.019	0.006	0.014	0.40
Second scoring	0.013[xy]	0.003[x]	0.005[x]	0.036[y]	0.011	0.05
Third scoring	0.018	0.012	0.016	0.034	0.012	0.62
Fourth scoring	0.052	0.000	0.032	0.058	0.020	0.10
Final scoring	0.050[yz]	0.021[w]	0.049[xz]	0.061[xy]	0.016	0.04
Flank Bites						
Initial scoring[c]	0.016	0.000	0.027	0.010	0.010	0.77
Second scoring	0.0180	0.0000	0.0000	0.0080	0.0098	0.19
Third scoring	0.012	0.022	0.016	0.004	0.014	0.52
Fourth scoring	0.022	0.084	0.036	0.080	0.044	0.84
Final scoring	0.069	0.144	0.119	0.124	0.051	0.87
Tail Bites						
Initial scoring[c]	0.0214	0.0043	0.0114	0.0171	0.0083	0.14
Second scoring	0.062	0.040	0.036	0.028	0.019	0.46
Third scoring	0.034	0.060	0.036	0.028	0.016	0.19
Fourth scoring	0.068	0.102	0.042	0.050	0.030	0.74
Final scoring	0.081	0.126	0.047	0.069	0.050	0.71
Leg Lesions						
Initial scoring[c]	0.101	0.049	0.116	0.073	0.035	0.10
Second scoring	0.034	0.030	0.094	0.068	0.027	0.47
Third scoring	0.100	0.150	0.188	0.118	0.079	0.49
Fourth scoring	0.202	0.212	0.278	0.290	0.088	0.65
Final scoring	0.23	0.44	0.32	0.38	0.15	0.41
Leg Bursa (% of pigs)						
Initial scoring[c]	25.8	20.6	27.5	21.4	4.9	0.40
Second scoring	28.5	31.3	33.0	31.3	6.4	0.20
Third scoring	36.8	26.9	27.2	28.3	3.8	0.53
Fourth scoring	28.5	21.3	25.4	25.0	3.9	0.20
Final scoring	21.8	7.9	11.0	18.0	4.5	0.60

[1] block 7 not included in analysis or data representation; blocks one and two included in initial and final scoring periods only

[a] SUC: small uncrowded, SC: small crowded, LUC: large uncrowded, LC: large crowded

[b] *P*-values are derived from analysis of the square root transformation of the raw data, except for leg bursa *P*-values, which have been derived from analysis of the sine transformation of the raw data

[c] initial scoring was taken after a habituation period of three days for blocks 1, 2, 6, and 8, and four days for blocks 3, 4, and 5

[wxyz] Means within the same row sharing a common superscript or having no superscript do not differ significantly ($P > 0.05$)

Pityriasis Rosea appears in the form of raised red circular papules with a central crater occurring mostly on the ventral abdomen and inner thighs. The papules gradually expand and become ring-shaped. It usually takes about four weeks for the lesions to heal, leaving normal skin behind (Cameron, 1999). Treatment does not appear to affect progression of the disease. While the cause of the disease is unknown, it appears to be inherited, since attempts to transmit the disease in other ways have failed (Cameron, 1999). The extent and severity of the lesions appear to increase when pigs are raised under high stocking densities with high temperature and humidity (Cameron, 1999).

During block three, the recorded room temperature exceeded 25 °C (the thermal comfort maximum of grower-finisher pigs; Table 1.4) for at least a week, with the exception of week two. During week six, a week prior to the disease outbreak, the recorded room temperature exceeded 25 °C on at least three days. It is possible that the thermoneutral maximum temperature was exceeded more often a week because temperatures were not recorded every day. The increase in temperature during block three may have been responsible for the disease outbreak.

Part way through block eight, a few pigs showed symptoms of a viral induced dermatitis caused by Porcine Circovirus, or more specifically, porcine dermatitis and nephropathy syndrome (PDNS). The resulting scab-like skin lesions are caused by a type three hypersensitivity (John Harding, DVM, personal communication). In other words, antibody-antigen complexes are deposited into the small capillaries of the skin and kidney. Gradually the skin lesions slough off and heal. The kidneys may become slightly swollen, but would grade well at slaughter (John Harding, DVM, personal communication). This disease did appear to stunt pig growth, but the animals appeared quite lively and healthy otherwise.

Although these illnesses were present during the study, no statistically significant effects of space allowance or group size were found on the proportion of animals receiving antibiotic treatment, or the proportion of animals that had to be removed from the trial due to illness or death. Similarly, there were no space allowance x group size interaction effects on either parameter. The total mortality rate within the study was 0.7 %, or 17 deaths out of a possible 2304 pigs. Mortality incidences were too low to differentiate between the treatments. The treatment and removal results are shown in Table B.4.

2.3.6 Salivary cortisol concentrations

Overall, there were no differences in salivary cortisol concentrations between the treatments. Upon examining a breakdown of the weeks, significant differences between the cortisol concentrations of the treatments still did not exist.

Samples from the first sampling period were analyzed individually rather than as a mixed sample so that it could be determined whether differences in cortisol concentrations existed when samples were taken in more or less than five minutes per pen. According to the results of the non-parametric Friedman tests, no differences existed. Because the Friedman test uses a ranking system to determine whether differences between the treatments exist, tables containing actual concentrations have not been shown.

2.3.7 Post mortem adrenal gland analysis

Space allowance did not affect any of the measurements taken from the adrenal glands analyzed. Group size only affected the gland weight:100 kg body weight ratio. Pigs housed in small groups had a smaller ratio than pigs housed in large groups (P = 0.03; Table 2.14). There were no group size x space allowance interaction effects for any of the gland measurements taken (Table B.5).

TABLE 2.14

Average of adrenal gland measurements taken from four randomly selected focal pigs in each treatment for blocks three through eight

	Space Allowance[a]		Group Size[a]			*P*-value	
Item	UC	C	S	L	SEM	Space	Group Size
# experimental units	12	12	12	12	—	—	—
# of pigs used	24	24	24	24	—	—	—
Cortex Area (cm^2)	0.511	0.470	0.460	0.521	0.022	0.22	0.07
Medulla Area (cm^2)	0.1006	0.1008	0.0993	0.1022	0.0045	> 0.95	0.65
Cortex area:Medulla area ratio	5.19	4.91	4.86	5.23	0.31	0.54	0.41
Total Area (cm^2)	0.612	0.571	0.559	0.623	0.023	0.24	0.07
Cortex area:Total area ratio	0.8323	0.8213	0.8211	0.8324	0.0086	0.38	0.37
Left Gland Weight (g)[b]	2.390	2.240	2.246	2.384	0.068	0.12	0.10
Live off-test BW (kg)[c]	97.2	92.4	96.3	93.3	1.9	0.09	0.30
Left gland weight (g)/100 kg BW	2.490	2.450	2.358	2.578	0.064	0.63	0.03

[a] UC: uncrowded, C: crowded, S: small group, L: large group

[b] *P*-values are derived from the analysis of the cosine transformation of the raw data

[c] The off-test body weight (BW) was not necessarily market weight due to random selection of the focal pigs for adrenal gland collection

2.3.8 Carcass measurements

Overall, neither space allowance nor group size had any effects on a particular carcass measurement. Furthermore, there were no interaction effects of space allowance and group size for lean depth. However, there were interactions of space and group size for carcass value index, percent lean yield, and fat depth ($P = 0.01$, $P = 0.02$, $P = 0.03$ respectively; Table 2.15). The small uncrowded group and the large crowded group had the highest carcass value index, while the small crowded and large uncrowded groups had the lowest scores (Table 2.15). The pairs did not differ from one another. The small uncrowded group had the highest percent lean yield, followed by the large crowded group, then the small crowded group, and last of all, the large uncrowded group. Each group did not differ from the group with the score closest to it (Table 2.15). The large uncrowded group had the highest fat depth, and it differed from all of the other treatments (Table 2.15). None of the other treatments differed from each other.

2.4 Discussion

2.4.1 Gender

The findings of Samarakone and Gonyou (2003) indicated that barrows gained more than gilts. Upon imposing a space restriction, a reduction in gain was more evident among barrows (Gonyou, 1999). Jensen et al. (1973) reported a similar response in performance due to space restriction for barrows and gilts. In the current study, barrows did experience higher gains than gilts. However, unlike the findings of Gonyou (1999), gains achieved by barrows were not reduced significantly more than that of gilts when a space restriction was imposed.

Literature stated that barrows were fatter than gilts when housed in crowded environments, suggesting a gender x space allowance interaction (Hamilton et al., 2003). In the current study, barrows did in fact have higher fat depths than gilts at slaughter, but this effect was noted overall and was not linked to space allowance or group size. Thus barrows did not appear to be more affected by space restriction than gilts.

TABLE 2.15

Carcass measurements taken from grower-finisher pigs in blocks one through six[1]

	Space Allowance[a]		Group Size[a]			Interaction[b]					*P*-value		
Item	UC	C	S	L	SEM	SUC	SC	LUC	LC	SEM	Space	Group Size	SP x GS
# experimental units	12	12	12	12	—	6	6	6	6	—	—	—	—
carcass value index	112.60	112.66	112.69	112.57	0.16	113.01[x]	112.37[y]	112.19[y]	112.95[x]	0.22	0.77	0.59	0.01
percent lean yield	59.872	59.876	59.884	59.864	0.082	60.04[rs]	59.73[tu]	59.71[u]	60.02[st]	0.12	> 0.95	0.86	0.02
loin fat depth (mm)	20.15	20.05	20.00	20.20	0.18	19.74[y]	20.26[y]	20.55[x]	19.85[y]	0.25	0.71	0.42	0.03
loin lean depth (mm)	61.74	61.21	61.11	61.83	0.38	61.86	60.36	61.62	62.05	0.54	0.34	0.20	0.09

[1] Blocks 7 & 8 not included in analysis of raw data

[a] UC: uncrowded, C: crowded, S: small group, L: large group

[b] SUC: small uncrowded treatment, SC: small crowded treatment, LUC: large crowded treatment, LC: large crowded treatment

[xy] Means within the same row with a common superscript, or with no superscript, do not differ significantly ($P > 0.05$)

[rstu] Means within the row with a common superscript do not differ significantly ($P > 0.10$)

Contrary to the findings of Partanen et al. (2004), there were no interactions of gender and group size or space allowance for lameness. Similarly, there were no interactions for other injuries. In fact, there were no significant differences in the injury scores of barrows and gilts whatsoever.

Perhaps a reason for the lack of interaction between gender and space allowance or group size is because of the small sample size of gilts. There were only 288 gilts divided into 12 pens, totalling 144 gilts for each space allowance treatment (6 pens each).

2.4.2 Productivity

2.4.2.1 Daily gain

Based on a review of the literature, it can be said that most studies have found a reduction in the daily gain of grower and finisher pigs when space allowance is reduced below k = 0.034 (Jensen et al., 1973; Ford and Teague, 1978; Meunier-Salaun et al., 1987; Pearce and Paterson, 1993; Brumm and NCR-89 Committee on Management of Swine, 1996; Brumm and Miller, 1996). A space allowance value of k = 0.034 has been previously determined to be the critical value at which performance begins to decrease for grower-finisher pigs (Gonyou et al., In Press). In the review conducted by Kornegay and Notter (1984), conclusions indicated that, within the range of space allowances assessed in the review, for grower pigs, every 0.1-m^2 increase in space above 0.3 m^2/pig (k = 0.021), daily gains increased by 5.2 %. For finisher pigs, every 0.1-m^2 increase in space above 0.7 m^2/pig (k = 0.034), daily gains increased by 2.6 %. Using their methodology to predict the reduction in gains for the current study, overall gains would have been expected to be reduced by approximately 5 %.

In the current study, space allowance did have a significant effect on daily gain. Overall, the daily gain of crowded pigs was 4.2 % less than that of uncrowded pigs. These findings generally agree with results from the growth-reduction predictions put forth by Kornegay and Notter (1984). By week four, the average body weight of the pigs in the crowded treatment (~ 65 kg) was such that the corresponding k value was beginning to dip below the predicted critical *k* value (*k* = 0.034) for the first time. It appeared that this initial phase of crowding caused the pigs to respond by decreasing their average daily gain for the first time. Afterwards, differences in gains between the two treatments were insignificant until the final week, at which time the pigs were most crowded and were reaching the minimum allowable *k* value for the study (*k* = 0.025). At that point, gains were reduced by 9.8 % in the crowded treatment.

When examining the effects of group size on gains, our results indicated that pigs housed in large groups gained 3.5 % less overall than pigs housed in small groups, resulting in a 3.0 % difference in final body weights. These results were similar to those found by Samarakone and Gonyou (2003b), who found that, overall, pigs housed in large groups gained 2 % less than pigs housed in small groups.

Initial weighing of the pigs served as a starting point after which calculation of average daily gain would provide insight into the effects of housing on pig performance. The 3.3 % smaller initial body weights of large group pigs may have been due to early setbacks that occurred during the habituation period, before the test period commenced. Examination of initial daily gain of large and small group pigs provided evidence that this theory was true. Pigs housed in small groups were outperforming their large group housed counterparts by a 5.4 % margin during the first week of the test period. Differences in daily gain during the following weeks were not significant. Samarakone and Gonyou (2003b) found that the large groups (108 pigs) were gaining 10 % less than the small groups (18 pigs) during the initial two weeks. Schmolke et al. (2003) found that overall daily gain was not affected by group size, but during the first two weeks, groups of 40 pigs were gaining 12 % less than groups of 10. For groups of 100 weanling pigs, live weight gains were reduced by up to 6 % in the period immediately post-weaning (Wolter et al., 2001; Wolter and Ellis, 2002).

Although there were no space allowance x group size interactions for daily gain, examination of the broken line analyses indicated differences in the responses of pigs housed in large and small groups to crowding. Pigs housed in small groups experienced reduced gains at *k* = 0.035 (~ 57 kg body weight), which is near the critical value of *k* = 0.034 pinpointed by Gonyou et al. (In Press). Pigs housed in large groups began to show reduced gains at *k* = 0.042 (~ 43 kg body weight). Therefore, it appears that pigs housed in large groups experience reduced performance due to crowding earlier than their small group housed counterparts. However, the effects of crowding in the large groups was much more gradual over time than it was in the small groups. Thus, the net result at the end of the trial showed minimal differences in the gains of pigs housed in small and large crowded groups, indicating that both group sizes are affected similarly by space restriction. This disproves the hypothesis of McGlone and Newby (1994), who proposed that pigs housed in large groups may perform better than pigs housed in small groups under restricted space allowances.

Within the swine industry there may lay concerns about the impact of production losses on economic returns. It is this author's opinion that production losses associated with large group housing could be countered by the costs averted by reduced input and labour requirements associated with large group housing. Costs averted by reduced labour inputs would be greatest with the use of automatic sort systems, as much of the work of a grow-finish technician lies in weighing and sorting pigs for market.

2.4.2.2 Feed intake

Kornegay and Notter (1984) and the NCR-89 Committee on Confinement Management of Swine (1993) hypothesized that reduced gains were due, in part, to reduced feed intake. Predictions put forth by Kornegay and Notter (1984) indicated that, within the range of space allowances assessed in their review, every 0.1-m^2 increase in the space allowance of finisher pigs above 0.7 m^2/pig (k = 0.034), increases feed intake by 2.3 %. However, the results of this study did not show an effect of space allowance on overall feed intake. The major shortcoming of the current study was the automated feed system experiencing problems on a number of occasions throughout the year that the study took place. There were also a few occasions in which feed scales had become faulty over time and had to be replaced, leaving technicians unsure of how much incorrect data had been recorded. The errors produced gave reason to discard some of the data, and may give reason to doubt the accuracy of the remaining data.

Past studies did not find significant differences in feed intake between grow-finish pigs housed in large and those housed in small groups (Spoolder et al., 1999; Wolter et al., 2001; Turner et al., 2002; Samarakone and Gonyou, 2003b; Schmolke et al., 2003). The findings of the current study support past studies. There were no significant differences in feed intake overall, or during any of the weeks throughout the trial. Furthermore, there were no space allowance x group size interactions for average daily feed intake.

The results of the current study suggest that reduced feed intake may not be a valid indicator of stress due to crowding. Although the feed intake data from pigs housed under differing space allowances does not agree with the literature, data from pigs housed in differing group sizes does. Examining feed efficiency data may provide further insight into the effects of space allowance and group size on grower-finisher pigs.

2.4.2.3 Feed efficiency

The results from the current study show that overall feed efficiency was lower for the crowded group pigs than the uncrowded group pigs. These findings were to be expected, as gains were also reduced among crowded pigs but feed intake remained the same. The first signs of reduced feed efficiency appeared in weeks three and four as crowding was first setting in. Following a pattern similar to that of weight gain, differences in feed efficiencies became insignificant during weeks five and six but became significant again during the final week. At that time, the feed efficiency of uncrowded pigs exceeded that of crowded pigs by 11 %. These results concur with those of Brumm and NCR-89 Committee on Management of Swine (1996), Brumm and Miller (1996), and Goihl (1996), who also found feed efficiency was reduced as space was restricted. This provided evidence that the feed intake data collected from pigs housed in different space allowances may have been accurate, although in conflict with some of the more recent industry findings (NCR-89 Committee on Confinement Management of Swine, 1993; Holck et al., 1998; Gonyou et al., 1999).

Overall, pigs housed in small groups were more efficient than pigs housed in large groups. These results are not supported by the literature, which found no differences in feed efficiency between large and small groups of weaner pigs (Wolter et al., 2000b; Wolter et al., 2001), or between large and small groups of grow-finish pigs (Spoolder et al., 1999; Schmolke et al., 2003). Pigs housed in large groups experienced lower initial gains than pigs housed in small groups, but the feed intake of the groups was not significantly different. This would be expected to result in a lower initial feed efficiency for the pigs housed in large groups compared with the pigs housed in small groups, which was, in fact, the case. However, no differences in gain or feed intake between the group sizes were found at the end of the trial, yet feed efficiency was lower for large group housed pigs. These results are unusual. Possible reasoning may be that minimal fluctuations in gains or feed intake may have been responsible for the significant decrease in efficiency. Wolter et al. (2001) found that pigs housed in groups of 50 and 100 experienced lower feed efficiencies than pigs housed in groups of 25 at week eight of their wean-to-finish trial. However, they found no differences from that point to the end of the trial (116 kg body weight), and they did not find differences in overall feed efficiency. Again, feed system malfunctions may be to blame for providing inaccurate feed intake data thus resulting in inaccurate feed efficiency calculation.

It was hypothesized that the performance of small group housed pigs would be more affected by crowding than that of large group housed pigs. The hypothesis was based on the McGlone and Newby (1994) hypothesis of a similar nature: as group size is increased, total space could be reduced without negatively affecting performance. Although the broken line analysis for gains disproved this hypothesis, this study did not report any space allowance x group size interactions for any of the performance parameters assessed, and a broken line analysis for feed intake and efficiency was not conducted. Frequent mention has been made to the feed system malfunctions. The impact of these malfunctions on the accuracy of the data is not known, and some data was discarded in order to maintain the accuracy of the remaining data to the best of our ability. However, replication of the feed intake portion of the study would be beneficial in order to make conclusions with the most confidence.

2.4.3 Behavioural time budgets

2.4.3.1 Feeding behaviour

The results of the current study indicated that, as the pigs grew, the proportion of time they dedicated to eating decreased. Gonyou and Lou (2000) also pointed out that older, bigger pigs spent less time eating.

The literature has indicated that pigs are observed eating more frequently when housed under restricted space allowances (Bryant and Ewbank, 1974). However, the results of the current study disagreed with that literature. The overall proportion of time spent eating in a 24-hour period was less for crowded pigs than it was for uncrowded pigs, although the proportion of time spent eating did not differ during any particular observation period. The degree of physical restriction imposed upon the pigs near the end of the trial may have been responsible for these results, as mobility was most restricted at that time. This hypothesis is supported by videotape data, which showed that crowded pigs ate 20 % fewer meals, had a lower total meal duration, and had a significantly higher latency to their next meal than uncrowded pigs, but only during the final observation when they were the most crowded. Hyun et al. (1998) noted that crowded pigs made 29 % fewer visits to the feeder when they subjected their pigs to $k = 0.017$. The greater degree of crowding, and thus, level of physical restriction, in their study could have been responsible for the greater decrease in feeder visits, and may have also been responsible for the fact that the decrease was significant overall, rather than just near the end of their trial.

Another reason for the greater decrease in feeder visits in the study conducted by Hyun et al. (1998) is that they tallied all feeder visits made by a pig, whereas we used a bout criteria interval of six minutes to define separate meals before calculating a tally. Crowding may cause a pig to choose to make significantly more feeder visits within a six minute interval than an uncrowded pig due to increased competition at the feeder or increased stress and frustration that may be associated with crowding. Statistical analysis on *all* eating events would then show that the overall number of bouts was significantly higher. Yet each eating bout is not necessarily a new meal. Use of a bout criteria interval enables the definition of separate meals and enables better insight into a pig's true eating behaviour than assessment of individual events would. The difference in the findings of the current study compared with those of Hyun et al. (1998) emphasizes the importance of a bout criteria interval in assessing feeding pattern data.

Findings in the literature also noted an increase in meal duration among crowded pigs (Ewbank and Bryant, 1972; Bryant and Ewbank, 1974; Meunier-Salaun et al., 1987; Hyun et al., 1998). However, the current study did not find similar results. Mean meal durations did not differ at all, and total durations only differed during the fourth period, at which time the total meal duration of uncrowded pigs was 17 % longer than that of crowded pigs. It is likely that pigs used in the literature studies spent more time eating because they accessed the feeder less often and made up for it by increasing each meal's duration. Bryant and Ewbank (1974) hypothesized that their pigs were not always using the increased time spent at the feeder for feed ingestion. Instead, the pigs may have been playing in the feeder. Their reasoning was based on evidence that average daily feed intake had decreased among the crowded pigs, despite the fact that crowded pigs were spending more time at the feeder. Similar play behaviour did not occur among crowded pigs in the current study or a difference in feed intake would have been noted.

Although a lot of the literature would disagree, the few differences in feeding patterns and the insignificant differences seen in feed intake between crowded and uncrowded pigs in the current study suggests that these variables are not always affected by the amount of space provided to a pig, but when affected, the difference occurs when the pigs are crowded to at least $k = 0.025$.

The hypothesis that increasing group size encourages feeding behaviour (Spoolder et al., 1999) was not proven in the current study. Pigs housed in large groups actually ate 22 % *fewer* meals overall than pigs housed in small groups, and overall latency to the next meal was longer for pigs housed in large groups by 25 %.

A hypothesis put forward by Wolter and Ellis (2002) suggested that placing the feeders in a single central location, as was done in the large groups in the current study, would increase competition for access to the feeder. Competition at the feeder was not assessed in the present study, but the differences in feeding patterns seen could be attributed to increased competition at the feeder. Pigs housed in large groups ate fewer meals, took longer to eat a meal, and had increased latencies between their meals compared with pigs housed in small groups. The fact that the proportion of time spent eating did not change overall, nor did it change at any particular point in the study (as indicated through 24-hour behaviour observations), further indicated that there may have been increased competition at the feeder because the pigs in large groups were ingesting similar amounts of feed as pigs in small groups, but in fewer meals. Perhaps if the feeders had been spread out in the large pens, group size differences in feeding patterns would have been non-existent. Another possibility is that we would have seen increased feeding behaviour in the large group, as was predicted by Spoolder et al. (1999).

There were relatively few group size x space allowance interaction effects for feeding patterns. Interactions were evident for overall mean meal and total meal durations. Pigs in the large uncrowded treatment had longer mean meal durations than pigs in any other treatment. The small groups did not differ from each other, nor did the crowded groups. Total meal duration was highest for pigs in the large uncrowded treatment as well, and did not differ for pigs in any of the other treatments. These findings suggest that effects of space restriction on feeding patterns are able to counterbalance the effects of group size on feeding patterns, causing a lack of effects to be seen when group size and space allowance interact.

2.4.3.2 Postural behaviour

The results of the current study indicate that, as the pigs grew, the proportion of time they dedicated to standing and lying ventrally decreased. Sitting behaviour was unaffected over time, and lateral lying behaviour increased. Overall, the lateral lying posture was the most common. Ekkel et al. (2003) also noted that pigs preferred to lie laterally, and spent more of their behavioural time budget in the lateral lying posture as they grew. While the most time spent standing and sitting was from 1300 to 1500, and the most time spent eating and lying ventrally was carried out from 1600 to 1800, lateral lying was the preferred posture from 0100 to 0600. Again, the findings on lateral lying posture agreed with those of Ekkel et al. (2003), who stated that lateral lying was most evident at night.

Pearce and Paterson (1993) reported that pigs were observed sitting or standing motionless more often when housed under restricted space allowances, and these behaviours are thought to be a strategy for coping with the stress of crowding. The behaviour of the crowded pigs in the current study did not indicate that they were experiencing a higher level of stress than uncrowded pigs, as overall sitting and standing behaviours were unaffected by the space allowance provided. The conflicting results of this study with those in the literature may be attributed to the fact that studies in the literature crowded their pigs beyond $k = 0.025$. The heightened stress experienced by the more crowded pigs in past studies may have been sufficient to alter their behaviour patterns, whereas in the current study, it was not.

According to the prediction equations provided by Petherick (1983), the amount of space required for a 40 kg pig to lie laterally is 0.54 m^2 whereas ventral lying only requires 0.22 m^2. Therefore, at the start of the current study, all pigs would have been able to lie in the preferred lateral position at the same time if they chose, regardless of the space treatment in which they were housed. The amount of space required for a 95 kg pig to lie laterally is 0.95 m^2 whereas ventral lying only requires 0.38 m^2. The value for lateral lying is likely high, as it assumes no sharing of the space around a pig's body. Ekkel et al. (2003) estimated that 40 % of the free space around a fully recumbent pig's body could be shared with penmates (Figure 1.2).

Using the prediction equations, the space allowance provided in the current study was such that only 25 % of the pigs in the crowded environment could lie laterally in the final week of the study if all pigs were lying down at the same time. So naturally, it was assumed that pigs would lie ventrally rather than laterally as space became more restricted in the crowded environment because the increasingly limited amount of space would force them to do so. Since pigs over 50 kg body weight will not tolerate overlying (Pearce and Paterson, 1993), compensating for the space restriction in that way was ruled out.

The findings of past research have supported this hypothesis (Meunier-Salaun et al., 1987; Pearce and Paterson, 1993). However, in actuality, overall lying behaviour was unaffected by space allowance. Lying behaviour was unaltered over time, with the exception of lateral lying behaviour during the second observation period (body weight

= 65 kg, k = 0.032). At that time, the lateral lying decreased among the crowded group pigs. The reason for the difference may have been because the k value was beginning to dip below the predicted critical value of k = 0.034, and so pigs were likely experiencing a physically noticeable degree of crowding for the first time. Perhaps the initial onset of space restriction elicited an amount of stress that only altered lateral lying behaviour for a brief period of time. Therefore, in subsequent periods, the differences in lateral lying behaviour would not become more pronounced.

Upon examination of lateral lying posture by time period, it could be seen that over 80 % of crowded pigs were lying laterally from 0100 to 0300 hours. Thus, either there was some space sharing occurring (i.e. the space surrounding the pig's body; see Figure 1.2), or there was some degree of overlying tolerated (possibly from the pigs' heads or legs) in order to compensate for the reduction in space.

Although the overall daily behaviour patterns were similar, the proportion of time uncrowded pigs spent standing from 1000 to 1200 and from 1300 to 1500 exceeded that of crowded pigs. From 1300 to 1500, crowded pigs dedicated more time to lying laterally than uncrowded pigs. Perhaps this suggests that crowded pigs choose to lie down rather than sit or stand motionless as a strategy to cope with the stress of crowding.

In more conventionally sized groups of 2, 4, 8, and 12 pigs per pen, Hyun and Ellis (2001) found that overall standing behaviour increased with increasing group size. However, Hyun and Ellis (2002) found no differences in the amount of time spent standing. Similarly, Spoolder et al. (1999), who studied groups of 20, 40, and 80 pigs per pen, and Schmolke et al. (2004), who studied groups of 10, 20, 40, and 80 pigs per pen, found no effects of group size on standing behaviour. The results of the current study agree with the findings of Spoolder et al., (1999), Hyun and Ellis (2002), and Schmolke et al. (2004).

The available literature did not find the differences in sitting or lying behaviours that the current study found. While the current study found that pigs housed in large groups sat for less time than pigs housed in small groups, no differences in sitting behaviour were found by Hyun and Ellis (2002) or Schmolke et al. (2004). Furthermore, the current study found that pigs housed in large groups spent less time lying ventrally and more time lying laterally than pigs housed in small groups, yet no differences in resting behaviour were found by Spoolder et al. (1999) or Schmolke et al. (2004). It should be noted that Spoolder et al. (1999) and Schmolke et al. (2004) did not define lateral and ventral lying as separate behaviours but instead, grouped them into one behaviour. This grouping of the behaviours may have been responsible for the lack of differences in resting behaviour seen in their studies.

McGlone and Newby (1994) proposed that a direct relationship existed between group size and the amount of free space available in a pen. Pigs housed in larger groups might have access to more free or unused space suggesting that, if group size is increased, total space allowance could be reduced without changing the free space available. In other words, provided similar space allowances, pigs housed in large groups would be able to make a more efficient use of space than pigs housed in small groups. The fact that pigs housed in large groups in the present study dedicated more time to lying in a fully recumbent, more space consuming posture than pigs housed in small groups provides support for this hypothesis. Since other research did not find differences in the resting behaviour of pigs housed in large and small groups (Spoolder et al., 1999; Schmolke et al., 2004), perhaps this suggests that pigs housed in large groups were able to use space more efficiently than pigs housed in small groups.

Examination of eating behaviour also provided useful insight into space use of large and small groups. Eating behaviour occurred more frequently in the large crowded groups than in the small crowded groups. These findings imply that pigs housed in large groups may have been able to manoeuvre around a space-restricted environment more easily than pigs housed in small groups. Furthermore, the proportion of time spent eating did not differ between the large crowded and large uncrowded groups. Perhaps this means that the space restriction imposed on a large group would have to be more intense than the restriction imposed on a small group in order to alter behaviour. The fact that literature on the behaviour of pigs in large (> 40 pigs/pen) versus small (< 40 pigs/pen) groups is limited makes definite conclusions on space use in these groups difficult.

Behaviour patterns in different group sizes may also be useful in predicting the level of stress present. In the current study, pigs in the large crowded group spent less time sitting than pigs in the small uncrowded group, and their sitting behaviour did not differ from the small crowded group. Using the 'inactive sitting as a coping strategy for stress' proposed by Pearce and Paterson (1993) as a basis, the lack of difference in sitting behaviour between the large and small crowded treatments in the current study implies that the stress levels of large group housed pigs were similar to that of small group housed pigs when space restrictions were imposed. Since sitting behaviour in large crowded groups occurred less than in small uncrowded groups, it appears that increased stress associated with large group housing was not present.

There is some discrepancy between the continuous observations (video data) and scan sampling (live observations) in terms of eating behaviour in this study. One reason may be the problems encountered when carrying out scan samples of the large groups. The clustering of the feeders and location of the technician when counting pigs eating made it difficult to count how many pigs were eating at the back portion of the feeders from the aisleway (see Figure 2.1 for room layout). Another reason for the discrepancy may be the length of the scan sampling interval. Possibly the interval (20 minutes) was too long to accurately assess the proportion of time a pig spent in a feeder, although the large number of replications should have been sufficient to make up for the long interval, since each experimental unit was scan sampled approximately 864 times throughout the trial. For this study, continuous observations may have been the more accurate assessment tool.

2.4.4 Injury scoring

The presence of the bursa on the olecranon joint(s) of a pig may be linked to the type of flooring the pig is housed on. The injury is a result of mechanical obstruction of the lymphatic system within the joint, causing reduced drainage of fluid (Detweiler, 1993). Pigs tend to develop such an injury when they reside on solid flooring. It is possible that when crowded, pigs may be more likely to develop such an injury because they are forced to lay ventrally more often. By lying ventrally, more pressure is put on the olecranon joints, which may result in an increased likelihood of blockage within the joint. Evaluating these types of injuries provides insight into the effects of social and housing conditions on health.

Baxter (1985b) stated that housing of livestock in increasingly confined conditions may lead to increased agonistic interactions and behavioural abnormalities. We, too, hypothesized that restricted space would increase vices such as tail and flank biting, and would be seen through higher tail and flank bite scores. Baxter (1985b) also stated that restricted space allowances add to the potential risk of physical trauma, and we hypothesized that this would be evidenced by higher lameness and leg lesion scores. Reduced mobility associated with restricted space may cause a decrease in activity and an increase in the amount of time spent in immobile postures, such as sitting and lying. This, in turn, would presumably result in a greater severity of leg lesions from increased rubbing of the pigs' legs on the concrete flooring. At the final scoring period, when the pigs were most crowded, only the leg lesion scores of crowded pigs were higher than that of uncrowded pigs. Overall, space allowance did not affect the severity of any injury assessed, suggesting that the degree of restriction in the current study may not have been sufficient to cause increased injury levels.

It was also presumed that tail biting would occur more frequently in crowded groups since crowded pigs are often more stressed than uncrowded pigs (Meunier-Salaun et al., 1987; Pearce and Paterson, 1993), and intolerable stress levels have been shown to influence the prevalence of tail biting (Schroder-Petersen et al., 2004). However, this was not the case. Tail biting scores were not affected by space restriction. Perhaps this is because the pigs in this study were not stressed. Another possibility is that the provision of environmental enrichment devices in the current study was able to reduce the prevalence of tail biting, as it has been shown to reduce harmful social behaviour in past research (Beattie et al., 1996). Since the causes of tail biting are still relatively obscure, one can say that perhaps space restriction alone does not actually influence the behaviour.

Literature findings have indicated that pigs housed in large groups experience increased lesion scores (Spoolder et al., 1999). However, the lesions scored in that study were those situated in areas most attacked by other pigs during a fight, such as around the ears, neck and shoulders. The occurrence of injuries such as leg lesions and flank bites has not been well documented in large groups of pigs. In the current study, flank bite scores were unaffected by group size, which may have been due, in part, to the provision of environmental enrichment devices. Higher leg lesion scores were recorded among large group housed pigs in the second injury scoring period and overall. The presence of leg bursa only differed among the group sizes during the second scoring period, at which time large groups had a higher incidence. Pigs housed in large groups may have experienced a higher score for these injuries because they spent more time lying laterally than pigs housed in small groups, which would have allowed their legs to rub on the concrete more frequently.

Pigs housed in large groups had higher lameness scores during the second and final scoring periods, as well as overall. One possible explanation may be that pigs in the large groups spent more time lying laterally than pigs in the small groups. This may have increased the occurrence of limb stiffness or lameness. Another possibility lies in the fact that large group housing allows more space for running. If the pigs' feet were to get caught in the slats while running, injury to the limb would be more likely. Casual observations of pigs running through a large group indicate that they run into walls and other pigs often, likely because they are traveling too fast to stop in time. This may also contribute to the higher incidence of lameness in such groups. Leg injuries to 'non-runners' may be a result of being stepped on or tripped over by 'runners'. The literature provided no possible explanation or previous findings on lameness within large groups of pigs.

The prevalence of tail biting within large groups has been more frequently documented. While Holmgren and Lundelheim (2004) found that tail biting increased when group size increased from 8 to 12 pigs per pen, studies comparing groups of 40 or more pigs found no differences in the prevalence of tail biting (Spoolder et al., 1999;

Wolter et al., 2000c; Schmolke et al., 2003). The current study agrees with the findings of these other large group studies. Tail biting scores did not differ among the group sizes.

Group size x space allowance interactions were evident for overall lameness scores. Differences in lameness scores were also evident during the second and final scoring periods. In every incidence, it was the large crowded group that had the highest score. A compounding effect of increased lying behaviour preferred by pigs in large groups and forced immobility imposed on pigs in a restricted space environment may be to blame. There were no interactions present for leg lesions, leg bursa, tail bites, or flank bites.

2.4.5 Animal morbidity

Neither space allowance nor group size had any effect on the number of animals that received treatment with antibiotics or the number of animals that had to be removed from the study. There were no group size x space interactions either. Although there were significant differences in leg lesion injury scores among pigs in small and large groups, lesion severity must not have justified antibiotic treatment or an animal's removal from the trial. Differences in lameness injury scores were also noted between the group size treatments. However, it is possible that the higher overall scores were due to a large number of low lameness scores that would not justify antibiotic treatment or animal removal, rather than a minimal number of high lameness scores that would justify treatment or removal.

These findings agree with the majority of the literature reviewed. Crowding did not significantly alter the level of morbidity (Edwards et al., 1988) or mortality (Meunier-Salaun et al., 1987; Brumm and Miller, 1996) in the grow-finish phase. Similarly, morbidity levels did not differ between large and small groups of grow-finish pigs (McGlone and Newby, 1994; Spoolder et al., 1999; Wolter and Ellis, 2002; Samarakone and Gonyou, 2003b; Schmolke et al., 2003). In the study carried out by Schmolke (2002), mortality rate was 0.8 %, a rate similar to that found in the current study (0.7 %).

2.4.6 Salivary cortisol concentrations

Salivary cortisol reflects circulating levels of free cortisol in the body, which is a reflection of the level of acute stress the animal is undergoing. A stressed animal more actively secretes cortisol from the adrenal gland, and levels of the hormone become apparent in the blood and saliva of that animal.

According to results obtained on salivary cortisol concentration analysis, there were no overall or weekly differences between the treatments. Furthermore, analysis on individual samples within the first sampling week did not indicate differences between the stress levels of pigs sampled in more versus less than five minutes of the technician entering the pen.

Past studies examining space allowance on pig stress levels were in agreement, finding no differences in cortisol concentrations of animals housed under restricted space allowances (Horton et al., 1991; Pearce and Paterson, 1993; Fisher et al., 1997a), although it was suggested that assessment of basal cortisol levels may have limited usefulness in predicting stress (Pearce and Paterson, 1993). One study in disagreement was that of Barnett et al. (1992), who crowded pregnant gilts and found higher levels of both free and plasma cortisol.

A study examining the effects of group size on stress found no differences in cortisol concentrations between groups of 108 pigs per pen and 18 pigs per pen (Samarakone, personal communication). Barnett et al. (1986) found higher total corticosteroid concentrations in gilts housed in pairs than gilts housed in groups of four or eight, but the difference in pig age, gender, and group sizes used could have been responsible for the contradictory findings between their study and the current study. The limited number of studies assessing stress levels in large versus small groups provides little evidence of the actual stress response that pigs would undergo in such environments.

2.4.7 Post mortem adrenal gland analysis

When an animal is stressed, it more actively secretes cortisol from the cortex of the adrenal gland (Freedman, 1975). Increased cortisol levels would be apparent in the blood and saliva until the animal was stressed to the point that its glands could not keep up with the cortisol requirement of the body. At that point, the glands would become fatigued and blood and salivary cortisol levels would decrease. Therefore, animals experiencing prolonged (chronic) stress may not necessarily have high levels of cortisol present in their saliva, but would still have larger and heavier adrenal glands due to the large amount of cortisol that had been required by the body (Freedman, 1975). More specifically, the cortex of their adrenal glands would be greater in size, and would be responsible for the increased weight of the gland.

The right adrenal gland weight of heifers was not significantly altered when the animals were crowded compared with the glands of heifers that were not crowded (Fisher et al., 1997b). To and Tamarin (1977) found greater adrenal gland weights as the population of *M. breweri* voles increased. However, their findings were species specific. Similar results were not found in populations of *M. pennsylvanicus* voles (To and Tamarin, 1977). In the current study, space allowance did not affect any of the measurements taken from the adrenal glands. This suggests that the crowded pigs were not chronically stressed.

The effects of group size in the current study were limited to the gland weight:100 kg BW ratio, with the large group pigs having the higher ratio. These findings disagreed with that of Samarakone (personal communication) who found no difference in the gland weight:100 kg BW ratio of pigs housed in large and small groups. In our study, the tendency ($P < 0.10$) of pigs housed in the large groups to have and heavier gland weights than small group pigs (likely due to greater cortex area and larger total gland area; $P < 0.10$), in conjunction with the insignificant differences in live off-test body weights in the two groups may have been sufficient to cause the large group pigs to have a greater gland weight:100 kg BW ratio. However, these findings are not sufficient to conclude that pigs in large groups were chronically stressed.

2.4.8 Carcass measurements

Since gains and feed efficiency were affected by both space allowance and group size, one would expect that fat and lean depth would also be affected. However, this was not the case. Neither space allowance nor group size were found to affect carcass value index, percent lean yield, loin fat depth or loin lean depth.

Discussions involving crowded versus uncrowded pig carcass data in the literature were conflicting. Holck et al. (1998) found that pigs crowded to $k = 0.030$ achieved only 70 % of the fat and lean gain that uncrowded pigs achieved. Crowded pigs had lower back fat levels in studies carried out by Burnham et al. (1995) and Brumm and NCR-89 Committee on Management of Swine (1996). Back fat levels were not affected in studies by Hugh and Reimer (1967) or Edwards et al. (1998). Back fat differences among varying group sizes were nonexistent (Wolter et al., 2001; Samarakone, personal communication), as were differences in lean depth (Samarakone, personal communication).

Due to welfare standards set by the Animal Care Committee, crowding partitions were removed when the crowded $k = 0.025$. In attempt to reduce the amount of compensatory gain achieved by the pigs after removal of the partitions, we only carried out statistical analysis on carcass data obtained from the first half of pigs that went to slaughter. However, it still took up to 41 days for the last pig in the sample to reach slaughter. Since literature on compensatory carcass gains is minimal, it is not known how this latency-to-marketing affected the carcass measurements of crowded treatment pigs. Had the pigs been crowded up to the point of slaughter, results may have differed. Since the group sizes remained intact until the pigs went to slaughter, the adequacy of those results has not been questioned.

3. CONCLUSIONS AND IMPLICATIONS

It has been suggested that grow-finish pigs housed in large groups would experience a number of performance and health problems due to decreased penmate recognition and increased agonistic behaviours. However, it appears that the deleterious effects of large group housing were few. Effects were generally confined to the initial adaptation period, and were limited to marginally reduced gains, non-debilitating injuries, and somewhat altered feeding patterns. For the most part, pigs housed in large groups were comparable to pigs housed in small groups. Marginal losses occurring at large group formation are likely to be recovered through reduced input and labour costs, mostly when automatic sort systems are used. Less penning and equipment is required in such a system. Also, much of a grow-finish technician's job is weighing and sorting market pigs, but in automated systems, there is no need for such manual labour.

The biggest concern raised in this study was the use of space in large groups, and whether it differed from that of small groups. It was hypothesized that the performance of pigs in small groups would be more affected by space restriction than that of pigs in large groups. However, the lack of interaction of group size and space allowance refutes this hypothesis. Broken line analyses showed that the gains of pigs in large groups, in response to space restriction, were depressed much earlier than the gains of pigs in small groups. However, the effect of space restriction on pigs in large groups was more gradual over time, and the net effect of crowding on gains at the end of the trial was similar for pigs in large and small groups. Differences in health and physiological (stress) variables were relatively non-existent throughout the trial. There was limited evidence, and none related to productivity, that pigs in large groups were able to use space more efficiently under crowded conditions than were pigs in small groups.

Before definite conclusions are made, replication of this study with increased focus on feed intake and prevalence of lameness is needed. Perhaps probing into the importance of environmental enrichment in such housing, and into the effects of such housing on levels of aggression, would be useful. In addition, the swine industry is encouraged to adopt the k value system since it reflects consistent space requirements applying to pigs over a range of body weights.

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APPENDIX A

TABLE A.1

List of nutrients present in the diets used throughout the study period

Diet[a]	Digestible Energy (kcal/kg)	Crude Protein (%)	Digestible Lysine (%)[b]	Calcium (%)	Total Phosphorus (%)	Available Phosphorus (%)
	Nutrient ('As Fed')					
Grower diet	3400	19.6	0.9	0.7	0.5	0.4
Gilt Finisher 1	3301	18.4	0.7	0.6	0.5	0.3
Gilt Finisher 2	3300	17.6	0.7	0.6	0.5	0.3
Barrow Finisher 1	3276	17.2	0.6	0.6	0.5	0.3
Barrow Finisher 2	3248	17.9	0.6	0.5	0.4	0.2

[a]The diet was balanced according to NRC requirements for lean growth potential. The primary energy source was wheat and the primary protein source was pea. Quantities varied depending on current market prices for the ingredients. Grower diet was fed from entry into grow-finish (35 kg) to 60 kg body weight, Gilt/Barrow Finisher 1 was fed from 60 to 90 kg body weight, Gilt/Barrow Finisher 2 was fed from 90 kg to market weight. Gilt Finisher diets were only fed in blocks 1 & 2 when gilts were involved in the study. Barrow Finisher diets were fed in blocks 3 through 8, inclusive.

[b]Values represent apparent ileal digestibility

TABLE A.2

Block pairs that ran simultaneously and their corresponding weeks

Block Pairs							
1	2	3	4	5	6	7	8
week 1	—	week 1	—	week 1	—	week 1	—
week 2	week 1	week 2[b]	week 1	week 2[abd]	week 1[a]	week 2[a]	—
week 3	week 2	week 3[ad]	week 2[ab]	week 3[c]	week 2[bcd]	week 3[bcd]	week 1[c]
week 4	week 3	week 4[bc]	week 3[cd]	week 4[abd]	week 3[a]	week 4[a]	week 2[abd]
week 5	week 4	week 5[ad]	week 4[ab]	week 5[c]	week 4[bcd]	week 5[bcd]	week 3[c]
week 6	week 5	week 6[bc]	week 5[cd]	week 6[abd]	week 5[a]	week 6[a]	week 4[abd]
week 7[b]	week 6	week 7[ad]	week 6[ab]	week 7[c]	week 6[bcd]	week 7[bcd]	week 5[c]
—	week 7[b]	week 8[bc]	week 7[cd]	week 8[abd]	week 7[a]	—	week 6[abd]
—	—	—	week 8[ab]	—	week 8[bd]	—	week 7
—	—	—	—	—	—	—	week 8[abd]

[a] saliva sampling took place

[b] injury scoring week; this represents scoring at the end of a week and does not include injury scoring that occurred the day pigs began the test phase

[c] 24-hour behaviour observation took place

[d] 24-hour videotaping event took place

TABLE A.3

Average body weights and the corresponding crowded *k* value for specific injury scoring periods, behaviour observation periods, videotaping observation periods, and saliva sampling periods

Item	Average Body Weight (kg)	$k_{Crowded}$
Injury Scoring Period[a]		
Initial[b]	37	0.047
Second[c]	50	0.038
Third[c]	66	0.032
Fourth[c]	80	0.028
Final	95	0.025
Postural Behaviour Observation Period[c]		
First	50	0.038
Second	65	0.032
Third	80	0.028
Fourth	92	0.025
Videotaping Observation Period[c]		
First	43	0.042
Second	65	0.032
Third	80	0.028
Fourth	95	0.025
Saliva Sampling Period[c]		
First	54	0.036
Second	69	0.031
Third	83	0.027
Fourth[d]	95	0.025

[a] block 7 not included because week weight deviated greatly from corresponding week in other blocks

[b] taken after a 3 or 4 day habituation period, depending on the block

[c] occurred in blocks three through eight only

[d] only blocks 4, 5, 6, and 8 were sampled during this period

APPENDIX B

TABLE B.1

Body weights with corresponding CV's, average daily gain, average daily feed intake, and feed efficiency of growing-finishing pigs housed at different group sizes and space allowance

	Interaction[a]					
Item	SUC	SC	LUC	LC	SEM	*P* -value
# experimental units	8	8	8	8	—	—
initial BW[b] (kg)	38.01	38.02	36.55	36.97	0.37	0.58
$CV_{initial\ BW}$	16.73	16.65	16.73	16.81	0.84	0.50
final BW (kg)	96.21	93.95	93.10	91.29	0.57	0.70
$CV_{final\ BW}$	11.79	11.07	10.76	11.45	0.50	0.18
overall ADG[c]	1.098	1.049	1.055	1.016	0.020	0.78
week 2	1.079	1.087	1.026	1.022	0.018	0.72
week 3	1.054	1.037	1.024	1.025	0.026	0.67
week 4	1.144	1.075	1.098	1.030	0.049	> 0.95
week 5	1.099	1.056	1.077	0.973	0.041	0.45
week 6	1.063	1.067	1.108	1.087	0.058	0.82
week 7	1.134	0.962	1.000	0.963	0.046	0.13
overall ADFI[c]	2.782	2.867	2.766	2.801	0.066	0.69
week 2	2.414	2.554	2.373	2.498	0.094	0.93
week 3	2.400	2.831	2.567	2.638	0.095	0.05
week 4	2.677	2.898	2.740	2.768	0.076	0.21
week 5	2.99	3.00	2.95	2.88	0.10	0.71
week 6	2.978	3.008	3.088	3.025	0.086	0.56
week 7	3.09	3.11	3.13	3.22	0.11	0.73
overall FE[c]	0.4108	0.3781	0.3807	0.3613	0.0080	0.38
week 2	0.458	0.424	0.430	0.403	0.017	0.84
week 3	0.441	0.381	0.406	0.385	0.018	0.27
week 4	0.429	0.392	0.401	0.371	0.018	0.76
week 5	0.392	0.384	0.366	0.354	0.016	0.90
week 6	0.358	0.363	0.361	0.359	0.021	0.85
week 7	0.390	0.329	0.323	0.303	0.014	0.12

[a] SUC: small uncrowded, SC: small crowded, LUC: large uncrowded, LC: large crowded

[b] taken after a habituation period of 3 days for blocks 1, 2, 6, and 8, four days for blocks 3, 4, and 5, and 10 days for block 7

[c] ADG: average daily gain (kg/day), ADFI: average daily feed intake (kg/day), FE: feed efficiency (kg gained per kg feed consumed)

TABLE B.2

Postural behaviour of grower-finisher pigs housed under differing space allowances and in differing group sizes, broken down into observation periods

	Space Allowance[a]		Group Size[a]			Interaction[b]					*P*-value		
Item	UC	C	S	L	SEM	SUC	SC	LUC	LC	SEM	Space	Group Size	SP x GS
# experimental units	12	12	12	12	—	6	6	6	6	—	—	—	—
Eating													
First observation	6.58	7.32	7.13	6.78	0.46	6.42	7.83	6.75	6.81	0.64	0.28	0.60	0.32
Second observation	5.55	5.98	5.71	5.82	0.35	5.53	5.89	5.57	6.07	0.47	0.35	0.81	0.88
Third observation	5.04	5.36	5.25	5.15	0.32	5.07	5.44	5.01	5.28	0.46	0.50	0.82	0.92
Fourth observation	4.86	4.54	4.45	4.95	0.49	4.64	4.26	5.08	4.82	0.69	0.66	0.50	0.93
Standing													
First observation	11.3	10.8	10.1	12.0	1.3	10.5	9.8	12.2	11.8	1.8	0.78	0.34	0.93
Second observation	8.80	7.57	7.59	8.78	0.81	8.0	7.2	9.6	8.0	1.1	0.22	0.24	0.70
Third observation	7.15	5.85	6.19	6.82	0.57	6.67	5.71	7.64	5.99	0.79	0.12	0.44	0.66
Fourth observation	6.79	5.39	6.18	6.01	0.78	7.2	5.1	6.3	5.7	1.1	0.25	0.89	0.53
Sitting													
First observation	2.82	3.55	3.51	2.85	0.39	3.14	3.88	2.49	3.21	0.54	0.23	0.27	> 0.95
Second observation	2.70	3.54	3.59	2.65	0.32	3.06	4.13	2.35	2.94	0.44	0.08	0.05	0.60
Third observation	2.41	3.02	3.05	2.38	0.29	2.84	3.26	1.98	2.78	0.41	0.16	0.13	0.66
Fourth observation	2.30	3.27	3.44	2.13	0.45	3.00	3.88	1.60	2.66	0.64	0.18	0.09	0.90
Lying Ventrally													
First observation	24.3	25.0	26.5	22.8	1.2	25.7	27.3	23.0	22.7	1.4	0.47	0.005	0.29
Second observation	23.8	23.2	24.5	22.5	1.1	24.7	24.3	23.0	22.0	1.3	0.37	0.01	0.65
Third observation	21.50	20.80	22.40	19.90	0.87	22.7	22.2	20.3	19.5	1.1	0.53	0.03	0.87
Fourth observation	20.3	19.3	20.7	19.0	1.1	21.0	20.3	19.7	18.3	1.2	0.28	0.10	0.71
Lying Laterally													
First observation	53.2	54.8	52.5	55.5	2.0	51.7	53.3	54.7	56.3	2.1	0.18	0.03	> 0.95
Second observation	58.2	60.8	58.6	60.3	1.9	57.2	60.0	59.2	61.5	2.0	0.01	0.08	0.79
Third observation	63.5	65.3	63.2	65.7	1.4	62.2	64.2	64.8	66.5	1.7	0.18	0.07	0.90
Fourth observation	66.2	67.0	65.2	68.0	1.3	65.7	64.7	66.7	69.3	1.5	0.46	0.04	0.13

[a] UC: uncrowded, C: crowded, S: small group, L: large group

[b] SUC: small uncrowded treatment, SC: small crowded treatment, LUC: large crowded treatment, LC: large crowded treatment

TABLE B.3

The interaction of space allowance and group size and the effects on proportion of time spent by grower-finisher pigs eating or in different postures within a given time period[1]

Item	Time Period	Interaction[a] SUC	SC	LUC	LC	SEM	*P*-value
# experimental units		6	6	6	6	—	—
Eating	0100 to 0300 hrs	2.89	3.09	2.66	2.33	0.61	0.79
(% of time)	0400 to 0600 hrs	1.99	2.96	2.49	2.45		
	0700 to 0900 hrs	7.56	7.71	7.73	7.81		
	1000 to 1200 hrs	6.93	7.26	7.37	7.18		
	1300 to 1500 hrs	8.79	8.54	8.80	8.83		
	1600 to 1800 hrs	8.97	9.67	9.39	10.13		
	1900 to 2100 hrs	3.73	4.25	3.15	3.93		
	2200 to 2400 hrs	2.47	3.35	3.21	3.31		
Standing[b]	0100 to 0300 hrs	2.5	2.5	3.0	2.6	1.4	0.86
(% of time)	0400 to 0600 hrs	1.9	1.7	2.4	2.1		
	0700 to 0900 hrs	9.5	7.6	9.9	10.2		
	1000 to 1200 hrs	10.7	7.8	11.1	8.8		
	1300 to 1500 hrs	19.0	14.6	19.7	14.7		
	1600 to 1800 hrs	14.6	14.1	17.4	17.1		
	1900 to 2100 hrs	4.0	4.2	4.3	3.7		
	2200 to 2400 hrs	2.7	3.1	3.7	3.6		
Sitting[b]	0100 to 0300 hrs	0.85	1.04	0.93	0.70	0.51	0.77
(% of time)	0400 to 0600 hrs	0.40	0.90	0.44	0.65		
	0700 to 0900 hrs	3.33	4.34	2.45	3.06		
	1000 to 1200 hrs	3.20	3.81	2.28	2.85		
	1300 to 1500 hrs	7.72	8.38	4.69	6.74		
	1600 to 1800 hrs	6.63	8.98	4.43	7.07		
	1900 to 2100 hrs	1.07	1.71	0.93	1.29		
	2200 to 2400 hrs	0.86	1.14	0.70	0.83		
Lying Ventrally	0100 to 0300 hrs	17.5	13.7	15.7	11.1	2.3	> 0.95
(% of time)	0400 to 0600 hrs	16.5	15.4	14.9	12.3		
	0700 to 0900 hrs	28.3	27.3	24.7	22.8		
	1000 to 1200 hrs	26.2	23.9	24.7	23.6		
	1300 to 1500 hrs	32.6	25.8	28.3	23.9		
	1600 to 1800 hrs	33.9	33.0	29.9	28.8		
	1900 to 2100 hrs	23.1	22.1	20.7	20.0		
	2200 to 2400 hrs	18.5	19.7	17.7	18.0		
Lying Laterally[c]	0100 to 0300 hrs	76.2	79.7	77.7	83.2	3.6	0.94
(% of time)	0400 to 0600 hrs	79.3	79.0	79.8	82.5		
	0700 to 0900 hrs	51.4	53.1	55.2	56.1		
	1000 to 1200 hrs	53.0	57.3	54.6	57.6		
	1300 to 1500 hrs	31.9	42.7	38.5	45.9		
	1600 to 1800 hrs	36.0	34.3	38.8	36.9		
	1900 to 2100 hrs	68.2	67.8	71.0	71.1		
	2200 to 2400 hrs	75.4	72.7	74.6	74.3		

[1] Values are an average for each time period taken at 2-week intervals from blocks 3 to 8

[a] SUC: small uncrowded, SC: small crowded, LUC: large uncrowded, LC: large crowded

[b,c] *P*-values are derived from analysis of the square root[b] or arcsine[c] transformation of raw data

TABLE B.4

The effects of space allowance, group size, and their interactions on the proportion of grower-finisher pigs receiving antibiotics for illnesses and the proportion of pigs requiring removal from the study for health reasons or mortality

	Space Allowance[a]		Group Size[a]		Interaction[b]				*P*-value		
Item	UC	C	S	L	SUC	SC	LUC	LC	Space	Group Size	SP x GS
# experimental units	16	16	16	16	8	8	8	8	—	—	—
% received medication											
lameness	3.73	6.08	4.34	5.09	3.82	4.86	3.70	6.48	0.53	0.51	0.81
other[c]	2.69	3.13	2.26	3.13	2.43	2.08	2.78	3.47	0.87	0.30	0.63
total	6.42	9.20	6.60	8.22	6.25	6.94	6.48	9.95	0.64	0.14	0.46
% removed from test											
lameness	0.95	1.65	0.87	1.45	0.69	1.04	1.04	1.85	0.25	0.21	0.40
tail bitten	1.04	0.61	1.04	0.75	1.74	0.35	0.81	0.69	0.58	0.63	0.39
other[c,d]	0.95	2.43	1.22	1.85	0.69	1.74	1.04	2.66	0.17	0.34	0.23
total	2.95	4.69	3.13	4.05	3.13	3.13	2.89	5.21	0.21	0.32	0.50

[a] UC: uncrowded, C: crowded, S: small group, L: large group

[b] SUC: small uncrowded treatment, SC: small crowded treatment, LUC: large crowded treatment, LC: large crowded treatment

[c] includes open wounds, abscess, hernia, rash, prolapse, coughing, and poor-doing pigs

[d] includes mortalities

TABLE B.5

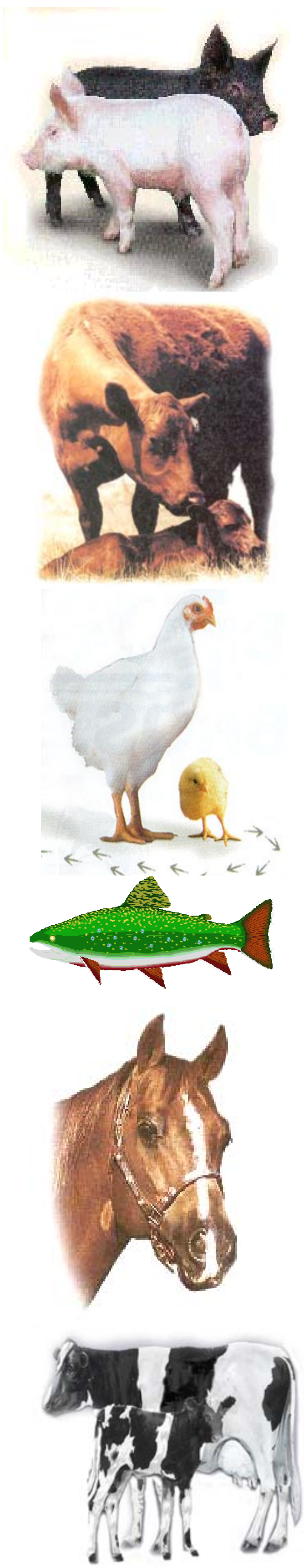
Adrenal gland measurements taken from four randomly selected focal pigs from each treatment group in blocks three through eight

	Interaction[a]					
Item	SUC	SC	LUC	LC	SEM	*P* -value
# experimental units	6	6	6	6	—	—
# of pigs used	12	12	12	12	—	—
Cortex Area (cm^2)	0.480	0.439	0.541	0.501	0.032	> 0.95
Medulla Area (cm^2)	0.0950	0.1035	0.1063	0.0982	0.0064	0.21
Cortex area:Medulla area ratio	5.20	4.52	5.17	5.30	0.44	0.37
Total Area (cm^2)	0.575	0.543	0.648	0.599	0.033	0.81
Cortex area:Total area ratio	0.833	0.809	0.832	0.833	0.012	0.32
Left Gland Weight (g)[b]	2.31	2.19	2.47	2.29	0.096	0.68
Live off-test BW (kg)[c]	96.2	96.3	98.3	88.4	2.7	0.08
Left gland weight (g)/100 kg BW	2.432	2.284	2.548	2.608	0.090	0.27

[a] SUC: small uncrowded treatment, SC: small crowded treatment, LUC: large crowded treatment, LC: large crowded treatment

[b] *P* -values are derived from the analysis of the cosine transformation of the raw data

[c] the off-test body weight (BW) was not necessarily market weight due to random selection of the focal pigs for adrenal gland collection



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