THE SOCIAL AND FEEDING BEHAVIOUR OF GROWING PIGS IN DEEP-LITTER, GROUP HOUSING SYSTEMS

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SUMMARY

Housing pigs in large pens using a floor base of deep litter has been developed as an alternative to conventional, indoor, intensive methods. Deep-litter, group housing systems are cheaper to establish and are perceived as being more “welfare- and environmentally friendly” for pigs compared to conventional intensive systems. However, recent industry records have shown that pigs housed in deep-litter systems have growth performance problems. In general, pigs are 10 percent less efficient in converting feed to live weight gain, are 1 to 2 mm fatter and exhibit more carcass damage (carcass bruising and non-infectious arthritis stifles joint damage) compared to conventionally housed pigs. It is possible that the growth performance problems in deep-litter systems are largely behavioural and possibly stress related, and pose a barrier to adoption of these systems by industry. This PhD program examined the social and feeding behaviour of entire male growing pigs in deep-litter systems in relation to their growth performance and stress physiology.

In Experiment 1, the behavioural repertoire, or ethogram, of entire male growing pigs in a deep-litter system and a conventional housing system was defined. The social behaviours and activity were pooled into the following categories; idle, locomotory (walking, frolicking and trotting), non-social, physical pen interactions (jump, nose pen fixtures, nosing concrete, rooting, rubbing and rolling), agonistic behaviours (parallel pressing, head-to-head knocks and levering), sexual behaviours (mounting) and social tactile interactions (anal nosing, nose-to-body, nose-to-nose and pushing). This ethogram was used to intensively study the social and feeding behaviour of growing pigs in subsequent experiments.

Experiment 2 studied the lying and locomotory behaviour of pigs and their relationship to stifles joint damage in a deep-litter system. The results showed that pigs do not consistently return to a particular area in the pen to lie (i.e. do not have a preferred lying area) and that stifles joint damage is not correlated with distance travelled in the pen.
Observations of the social and feeding behaviour of pigs housed in a deep-litter and conventional system were conducted in Experiment 3. Pigs in the deep-litter system spent less time within 1m of the feeder, had fewer feeding bouts and a longer duration of feeding bouts compared to pigs in the conventional system. Pigs in the deep-litter system also had a lower frequency of social interactions around the feeder than those in the conventional housing system, which may have caused less interruptions during feeding for pigs in the deep-litter system.

The results of Experiment 3 indicate that pigs in deep-litter systems may perform feeding behaviour in a relatively unrestricted manner and it may be possible that this change in feeding pattern may be responsible for the reported depressions in growth performance of commercial deep-litter housed pigs. Nutritional studies have shown that shorter, more frequent feeding bouts, as occurs in conventional systems, reduce fat deposition and improve conversion of feed to growth (feed:gain).

The possibility that the relatively unrestricted feeding in the deep-litter system was a factor in the increased fat deposition and poorer feed:gain was examined in Experiment 4. This experiment tested the hypothesis that longer but less frequent feeding bouts in deep-litter, group housing systems contribute to poor growth performance of pigs in these systems. Two factors that have the potential to change feeding behaviour by influencing the number of social tactile interactions either at or away from the feeder in a deep-litter system were studied: pen space and feeder availability. Reducing either space in the pen or feeder space failed to increase the number of feeding bouts or decrease the duration of feeding bouts. However, a reduction in pen space resulted in leaner pigs of a lower dressing percentage. While this effect may be a consequence of stress, it appears unrelated to feeding behaviour since pen space had no effect on feeding behaviour.
Housing pigs in large groups may result in an increase in social stress, due to an unstable social structure. The scientific literature suggests that neuroendocrine responses such as elevated concentrations of catecholamines (e.g. adrenaline), adrenocorticotrophic hormone (ACTH) and corticosteroids (e.g. cortisol) are known to have effects on efficiency of growth, fat and protein distribution, fat mobilisation and organ weights. In Experiment 5 the influence of social stress was simulated by treatment with daily intramuscular injections of 100 IU of ACTH. The influence of ACTH on fat mobilisation and distribution in the carcass, organ weight and growth performance of growing pigs was studied. The effects of the ACTH treatment were similar to those growth performance problems seen in deep-litter systems. The pigs in the ACTH treatment were fatter, had a higher daily feed intake and had a higher rate of gain compared to those in the control treatment. Therefore, if pigs in deep-litter systems experience greater social stress than those in conventional pens, stress may be at least partly responsible for the poor growth performance.

This thesis investigated the social and feeding behaviour, stress physiology and growth performance of entire male growing pigs in deep-litter, group housing systems. Comparison of pigs in deep-litter and conventional systems indicated a number of differences in the social and feeding behaviour, which may adversely influence the growth performance of pigs in deep-litter systems. The results from these experiments have shown that there may be a multitude of factors such as social and feeding behaviour and stress physiology that influence the growth performance of growing pigs in deep-litter systems.

One interpretation of the increase in social tactile interactions in deep-litter systems is that pigs in large groups may not have a stable social structure, perhaps because of the inability of pigs to recognise each other in large groups. The frequent interactions with possibly unfamiliar pigs may result in activation of the hypothalamic-pituitary adrenal axis (HPA) and in turn increased feed intake, fat deposition and carcass damage and bruising.
Alternatively or in conjunction, feeding behaviour of pigs in deep-litter group housing systems may influence growth performance. Pigs in a deep-litter system visit the feeder less frequently but for longer feeding bouts than pigs in conventional systems. The increased distance to the feeders in deep litter systems may discourage pigs from frequently visiting the feeders due to reduced social facilitation to eat, increased social interaction with unfamiliar pigs when moving to the feeder and greater locomotion required to reach the feeders. Clearly, further rigorous investigation is required to examine the effects of such factors on the social and feeding behaviour, stress physiology and growth performance of pigs in deep-litter, group housing systems.
DECLARATION

This is to certify that

(i) the thesis comprises only my original work, except where indicated in the preface,

(ii) due acknowledgment has been made in the text to all other material used,

(iii) the thesis is less than 100,000 words in length, exclusive of tables, maps, bibliographies and appendices.

REBECCA SARGENT

A list of published papers and conference proceedings arising from the research contained in this thesis is presented in the Appendix.
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The experimental work reported in this thesis was conducted at Bunge Meat Industries Ltd., (Balpool, Gre Gre-St Arnaud and Corowa sites), Australia, while I was enrolled as a PhD student with the Animal Welfare Centre, Department of Animal Production, Institute of Land and Food Resources at the University of Melbourne, Australia. My supervisors, Prof. P.H. Hemsworth, Dr. R.G. Campbell and Dr. G.M. Cronin, are gratefully acknowledged for their support, motivation and guidance throughout my candidature.

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GENERAL INTRODUCTION

Deep-litter, group housing systems have been developed as an alternative to intensive housing systems for growing pigs. Pigs are often housed in groups on deep-litter from 2 weeks of age at approximately 5kg in weight, to slaughter at 23 weeks of age at a weight of approximately 110kg. Conventionally, growing pigs are housed in a more confined housing system. These conventional systems are indoors and have an automated ventilation system, fully- or partially-slatted floors and liquid manure handling systems. The number of pigs per pen tends to be in the range of 5 to 50 pigs with a floor space allowance of a maximum of 0.7m² per pig. Thus, pen sizes tend to be small relative to the alternative housing systems. In contrast, deep-litter systems are naturally ventilated, have a floor base of deep litter consisting of rice hulls or straw, consist of larger group sizes (ranging from 150 to 2000 pigs per pen) and the pigs have a greater space allowance of approximately 1m² per pig. The housing of pigs in large groups offers more total space to individual pigs, which results in the pigs having a greater degree of choice over their own microenvironment than pigs in smaller groups in smaller pens (Spoolder et al., 1999).

The first deep-litter system (The Ishigami System®) was developed in Japan in 1970. This system consisted of a polyvinyl-covered tunnel house with sawdust deep-litter (Gadd, 1993). In 1985 straw-based deep-litter systems were developed in Canada. The BioTech® deep-litter system consisted of tubular steel framing with a plastic cover, timber side barriers, earthen floors and a concrete feeding pad at one end of the shed. The earthen floor was deep bedded and was cleaned out after each group of pigs (Connor, 1994). Deep-litter systems, similar in structure to the original systems developed in Canada (Clearspan® and EcoShelter®) have been developed in the Australian pig industry over the past six years (Payne et al., 2000). These systems are cheaper to establish, are perceived as being more "welfare-friendly" for pigs and more environmentally-sustainable, as the need for effluent ponds is eliminated and the deep-litter substrate is sold as a natural fertiliser.
Recent industry records have shown that pigs grown from 2 weeks of age to slaughter at 23 weeks of age in deep-litter systems have the following growth performance problems compared to conventionally housed pigs:

- Pigs are 10 percent less efficient in converting feed provided to live weight gain (feed:gain),
- Pigs are 1 to 2 mm fatter (back fat measurement at the P2 location),
- There is increased incidence of bruising and non-arthritis stifle joint damage, resulting in a devaluation of the carcasses (Payne, 1997; Connor, 1995; Brumm, 1999; Honeyman et al., 1999; Payne et al., 2000).

It is difficult to compare performance data obtained from experiments conducted on pigs in deep-litter systems because a variety of deep-litter systems have been used. Systems vary in the type and amount of bedding, the number of pigs per group, floor space allowance per pig, method of providing feed and water and the construction materials used to build the deep-litter system. Few rigorous comparisons have been conducted between the various modifications of deep-litter systems or between deep-litter and conventional systems. Nevertheless, while many key factors in addition to the basic features of the system will vary such as climate, disease status and location, it is possible that the apparent production differences between deep-litter and conventional housing systems are largely behavioural and possibly stress related.

The limited scientific literature and extensive industry experience indicate poor growth performance of pigs in deep-litter systems. In addition to possible welfare implications associated with stress or injury and lameness, there are growth performance problems that have the potential to limit the adoption of these systems by pork producers. Research is clearly required and this thesis focuses on the causes of these growth performance problems. To compare deep-litter systems with conventional systems, it is necessary to conduct controlled experiments, in which inputs unrelated to the system, such as locality, feed, feeder type and genetics are similar. Therefore, the aim of this thesis was to examine the social and feeding behaviour of entire male growing pigs in deep-litter, group housing systems in relation to their growth performance and stress physiology.
LITERATURE REVIEW

1. THE SOCIAL BEHAVIOUR OF PIGS

Animals behave in ways to maximise their individual fitness, which will ultimately enable their genes to spread (Manning and Stamp Dawkins, 1992). Group living enables animals to maximise their chance of survival, as animals living in a group can detect food and predators quicker. However, animals within a group have to compete with each other for available resources, such as mates, food and shelter. A large amount of population dynamics occurs within social groups as animals shift balances between these costs and benefits, which ultimately helps to regulate the size of the group and population density (Stricklin and Mench, 1987). An understanding of the social behaviour and organisation of pigs living in a group is essential when studying the social behaviour of pigs in deep-litter, group housing systems. Furthermore, this knowledge of social behaviour is critical when attempting to achieve optimum growth performance in any pork production system.

The social structure of the wild pig, Sus scrofa is the matriarchal herd, which consists of up to four females with their offspring. The mature boars are not permanently associated with the herd and often form ‘bachelor’ groups or remain alone (Signoret et al., 1975). Stolba and Wood-Gush (1989) observed this social structure in intensively-reared domestic pigs living under natural conditions. Domestication has modified this free-ranging foraging pig to a more docile animal (Sus scrofa domestica), which is raised under intensive farming conditions (Signoret et al., 1975).

The social behaviour of growing pigs has been defined by Kelley et al. (1980), McGlone (1984, 1985) and Stolba and Wood-Gush (1989) and in group-housed dry sows by Jensen (1980, 1982). The social behaviours of pigs can be categorised into social tactile interactions, agonistic behaviours, sexual behaviour and social grooming.
Social tactile interactions are important in maintaining social organisation. Pigs are often described as 'contact' animals, which usually have tactile contact with other pigs when resting (Hafez, 1975). Social tactile interactions such as nose-to-body, nose-to-nose and anal nosing have been described in growing pigs by Signoret et al. (1975) and in group-housed dry-sows by Jensen (1980, 1982). Jensen (1980) concluded that these behaviours are involved in individual animal recognition through olfactory and tactile cues and these behaviours are important when groups of animals need to establish effective competitive and cooperative social relationships (Stricklin and Mench, 1987).

Agonistic behaviours are a series of behaviours that occur in response to a conflict, and include offence, defence, submissive or escape components. The behaviours may include contact (e.g. biting or pushing) or non-contact (e.g. body postures or gestures). Aggressive behaviour is a component of agonistic behaviour, and includes contact and threatening behaviours (Petherick and Blackshaw, 1987). Aggressive behaviour is often used interchangeably with agonistic behaviour and in the strict definition aggressive behaviour refers to the attack and actual fighting (Hart, 1985; Fraser and Broom, 1998). Parallel pressing, head-to-head knocks and levering are defined as aggressive behaviours, which have been reported by McBride et al. (1964), Beilharz and Cox (1967), Hafez and Signoret (1969), Signoret et al. (1975), Jensen (1980) and Fraser and Broom (1998). Head-to-head knocks have also been found as a component of play behaviour by van Putten and Dammers (1976). Agonistic behaviour in entire males has also been described by Hafez and Signoret (1969) and the authors considered agonistic behaviours to be part of the establishment of the social hierarchy. There is inconsistency within the scientific literature in terms of definitions of aggressive behaviours (McGlone, 1986). For example, Friend et al. (1983) defined fights as aggressive behaviours with a duration less than 3 seconds, whereas (Rushen and Pajor, 1987) defined fights as an aggressive encounter with a duration greater than 15 seconds.
Mounting is described as a sexual behaviour and visual cues initiate this behaviour. It is not unusual for entire males reared in groups to form stable homosexual relationships (Signoreti et al., 1975; Fraser and Broom, 1998).

Social grooming rarely occurs among pigs, however this behaviour has been observed by Krosniunas (1979) and Stolba and Wood-Gush (1989). Pigs in a semi-natural environment formed small subgroups of the female with her offspring or other females and performed social grooming. It was concluded that this behaviour may be involved in maintaining social bonds within the social organisation. Pigs will rub against pen fixtures or upright objects and this may be considered part of their grooming behaviour (Signoreti et al., 1975).

An ethogram of the social behaviours of pigs in deep-litter and conventional housing systems will be defined in this thesis. Furthermore, these social behaviours will be measured and relationships between social behaviours and growth performance of pigs in deep-litter systems will be examined.

1.1 Dominance hierarchy

Domestic pigs organise and maintain a dominance hierarchy throughout their life. The function of the dominance hierarchy is to reduce aggression within the social group when resources are limited. A frequently used definition is “priority of access to an approach to resources or away from an avoidance situation” (Stricklin and Mench, 1987). The social organisation of pigs usually reflects a dominant and subordinate relationship (Hart, 1985). Dominance-submission relationships occur when there is a consistent relationship as the result of agonistic reactions between two pigs (Puppe, 1996). Two types of social organisation have been described in the domestic pig: the teat order within a litter of piglets and the dominance hierarchy, which is established after weaning (Signoreti et al., 1975).
The teat order develops soon after birth and remains relatively stable to weaning, which enables efficient milk intake. Piglets appear to compete for the more productive anterior teats of the sow (McBride, 1963). If the teat order and dominance order were the same, stable dominance hierarchy may occur throughout life if the pigs were kept together (Ewbank, 1976). However, pigs are generally mixed in commercial pork production systems, particularly prior to and after weaning. This mixing enables pigs of similar body weight and sex to be housed together so that nutritional demands can be met. The current scientific literature investigating the social hierarchies in pigs suggests that the dominance hierarchy is established during periods of high levels of agonistic behaviour immediately after mixing.

The structure of the dominance hierarchy is usually linear especially in smaller groups at low stocking densities (Ewbank, 1969, 1976). In an established linear hierarchy the animal occupying the top-rank will take precedence in a competitive situation (e.g. feeding) without fighting any animals in the group. The second in the linear hierarchy will be submissive to the first but will be dominant over the rest. This linearity continues, with ultimately the animal on the lowest level submissive to all others i.e. A>B>C>D>E>F. However, it is also possible for two animals to occupy the same position on the linear hierarchy and sometimes dominance “circles” will be seen i.e. A>B>C=D>E>F. Sometimes special relationships may be seen in which a pig may dominate an animal which, in relation to the rest of the group is above it in social rank, i.e. A>B>C>D>E>F>G, but F dominates D. This relationship is termed ‘triangular’ (Signoret et al., 1975). McBride et al. (1964) reported that the social order among males seemed to be less stable than among females as males of intermediate rank positions fought regularly. Beilharz and Cox (1967) found stable social hierarchies in pigs raised together as complete litters from birth, and showed that males were usually dominant over females. On the other hand, Meese and Ewbank (1973) found that there was no correlation between social rank and sex.
McBride et al. (1964) described three types of behaviour involved in the creation of the dominance hierarchy, especially in confined areas. The behaviours included (i) intra-specific aggressiveness, (ii) submission signals and (iii) an acceptance of submission. When two previously unacquainted pigs are placed in a competitive situation for resources, they will fight and eventually one will win and the other will lose. This process is repeated on subsequent occasions, and eventually the habitual loser responds to a mere threat of attack with submissive behaviour (Signoret et al., 1975).

Meese and Ewbank (1972) suggested that a linear social hierarchy may not be as stable as previously assumed. Pigs alter position in the hierarchy frequently and without prior warning, especially in the middle or lower ranks of the hierarchy. Nevertheless, rarely does the most dominant pig change position. These changes to the hierarchy have been observed in pigs housed in extensive systems as well as in pigs kept indoors (Meese and Ewbank, 1972).

The dominance hierarchy is perhaps the most recognised form of social organisation in farm animals, although there are other types of social hierarchies involved in groups of animals. Leadership-followship orders have been described in dairy cattle, where certain animals in the group initiate voluntary movements such as moving towards the milking shed, even though these cows do not occupy the top position in the dominance hierarchy. While it was originally thought that this pattern of behaviour could only be seen in grazing herd animals, Ewbank (1976) suggested that pigs housed in enriched environments develop leadership hierarchies. Certain individuals in the group initiate activities and others imitate them, even though the initiator is not necessarily highly ranked in the dominance order. As this type of behaviour is difficult to observe, it may be difficult to detect in crowded, intensive housing systems. This leadership-followship behaviour may be more readily observed in deep-litter systems where the pigs have much more space compared to conventional systems.
There is limited scientific literature on the establishment of social dominance in large groups of pigs housed in deep-litter systems. This thesis will study the social behaviour of pigs housed in deep-litter systems, which may provide a clearer understanding of the social structure in large groups of pigs.

1.2 Cues of social recognition

In order for a group of animals to establish effective competitive and cooperative social relationships it is necessary for the animals within the group to promptly identify and communicate with each other (Stricklin and Mench, 1987). A common estimate of the total number of group members that can be recognised by an individual is 20 to 30 in pigs and 50 to 70 in cattle (Fraser and Broom, 1998). Cues of social recognition are essential for the survival of individuals and ultimately the species because these cues relate to reproduction, maternal behaviour, protection and learning (Ewing et al., 1999). The scientific literature is still somewhat unclear on how the mechanism of individual animal recognition operates in pigs, although it is evident that different cues of social recognition exist (Fraser and Broom, 1998).

It appears that when pigs identify individuals within a group, auditory, olfactory, tactile and visual cues are important (Hart, 1985; Stricklin and Mench, 1987). Research has shown the importance of auditory cues in the organisation of social behaviour. The auditory range in pigs is from approximately 55Hz to 40 kHz and the pigs are most sensitive from 500Hz to 16kHz (Ewing et al., 1999). More than 20 different auditory cues have been identified in the pig during social encounters such as resting, play, feeding, maternal, agonistic and sexual behaviours (Ewing et al., 1999).

Common auditory signals are grunts, barks, squeals and screams. Longer grunts are expressed in response to a familiar sound, and shorter length grunts are typical in excited pigs. As the pigs become more excited, the grunting frequency increases. Squeals and screams are associated with high levels of fear and barks are expressed when the pig is surprised or expressing dominance behaviour (Houpt, 1991).
Pigs have well-developed hearing, which requires movement of the head to locate the sound, as the ears are short and immovable (Signoret et al., 1975). McBride et al. (1964) have suggested that auditory cues may be used as a submission signal, and pigs may be able to recognise sounds from specific individuals.

Pigs have highly developed olfactory capability (Ewing et al., 1999), which is important for social recognition and feeding behaviour. McBride (1963) has suggested that piglets may show marking behaviour which assists in locating their position in the teat order. Boars determine mating receptivity of females using the vomeronasal organ as well as observing sexual behaviour (Ewing et al., 1999).

Vision is well developed in pigs as they have cones (duplex retina) and rods in the eyes which gives rise to high sensitivity and high acuity, and suggests the capability for colour vision (Ewing et al., 1999). Ewbank (1974) studied the importance of vision and olfactory cues in the formation of social hierarchy. When opaque lenses were fitted over the pigs’ eyes, the pigs formed a stable social hierarchy, however when the whole head was covered social hierarchies were not formed, which suggests that olfactory cues are involved in social recognition. Individual recognition is also assisted by vision, since hierarchies were also formed when eyes were uncovered.

Hafez (1975) suggested that vision is certainly involved in sexual behaviour and Rasmussen et al. (1962) have also suggested that visual cues are involved in individual animal recognition in pigs.

An understanding of the cues of social recognition is essential in the study of the social behaviour of pigs. There is limited scientific literature on whether cues of social recognition are still functional and successful in allowing individual animal recognition in large groups of pigs in deep-litter systems. This area of research is poor in the scientific literature and requires further investigation.
1.3 Factors affecting social behaviour and implications for growth performance

1.3.1 Social factors

The social environment has a significant effect on the growth performance of the pig and some of the important features of the social environment in relation to growth performance will be reviewed here.

 Dominance hierarchy

Domesticated pigs are kept in groups of similar age and sex. Research has shown that social structure affects the growth performance of individuals within the group (Morgan et al., 1999). Commercial intensive pig production may disrupt the social hierarchy as pigs may be frequently mixed with strange animals in order to maintain uniform groups of the same sex, age or weight. Ewbank and Meese (1971) conducted experiments in which pigs of varying social rank were removed from a stable hierarchy. The behaviour of the pigs was observed when they were returned to the group. Removal of pigs did not alter the social hierarchy or the amount of agonistic interactions within the rest of the group, although it was found that the time a pig could be removed without being attacked upon its return varied with its social rank. Top-ranking animals could be returned after 25 days of separation from the group, but lower ranked animals were attacked three days after separation.

Otten et al. (1997) investigated agonistic interactions and physiological reactions of top- and bottom-ranking pigs confronted with a familiar and an unfamiliar group of pigs. In general, the confrontation with an unfamiliar group caused frequent agonistic interactions between the animals during the first 30 minutes. Top-ranked animals were involved in more agonistic interactions than bottom-ranked pigs. Similar results were found in an experiment conducted by Hessing et al. (1994). In addition, exposure to the unfamiliar group resulted in a more pronounced release of cortisol one hour after introduction compared to the familiar group. This suggests higher levels of acute stress when pigs were confronted with an unfamiliar group. Pfister (1979) and Haemisch (1990) also showed that confrontation of an individual to an unfamiliar environment caused enhanced adrenocortical reaction.
Haemisch (1990) showed that plasma cortisol concentration one hour after introduction was higher in top-ranked pigs compared to lower-ranked pigs when faced with an unfamiliar group, and continued to remain elevated until returning to base levels 10 hours after the introduction. These findings were also supported by Hessing et al. (1994) and Fernandez et al. (1994). Such disruptions to social behaviour have the potential to depress growth performance at least in the short term.

McBride (1960) provided evidence that the position in the social order did not affect growth performance of poultry if the husbandry conditions were optimum. However, growth performance of birds at the bottom of the social order was reduced when husbandry conditions were sub-optimal. The possibility of a similar situation occurring in pigs prompted McBride et al. (1964) to observe social behaviour of growing pigs and relate social order to growth performance. They found that high ranking pigs performed better than lower ranked animals. Thus social rank may have an appreciable effect on growth performance. Hansen et al. (1982) found that social rank was positively correlated with initial weight and the contribution of social rank to the total variance in growth from 8 to 16 weeks of age was estimated to be about 13 percent. Beilharz and Cox (1967) also reported positive correlations between dominance rank and growth performance. Nielsen et al. (1995b) found no relationship between dominance rank and growth performance when pigs had a high space allowance and were provided with straw.

Meese and Ewbank (1973) studied the establishment and nature of the dominance hierarchy by mixing groups of eight previously unacquainted pigs. The pigs fought vigorously within the first 24 hours and the group could be ranked by 48 hours. The most dominant animal was identified within an hour. It was found that there was no correlation between social rank, sex and growth performance and the authors suggested that social rank is determined by a combination of factors such as physical conformity, previous experience, sex, genetic factors, environment and the identity of other group members.
Therefore there is disagreement in the scientific literature with regard to the correlation between dominance rank and performance. Meese and Ewbank (1973) suggested that this could be due to our inability to properly describe the social organization of groups of pigs.

The dominance hierarchy in pigs has received considerable attention from researchers, but most of the research has been conducted on pigs in conventional systems and not in large group sizes of 200 or more pigs. It is unknown whether a dominance hierarchy exists in large groups of pigs, that is whether the cues of social recognition are still functional to enable dominance hierarchies to be formed. Ewbank (1969) suggested that the maximum number of pigs kept in a pen should be the same as the number of individuals that can organise themselves into a behaviourally-stable group. The impact of large group sizes on aggressive behaviour, the dominance hierarchy and in turn growth performance is unknown and requires further scientific investigation.

*Group size*

A large number of experiments have been conducted on the effect of group size on pig growth performance (Jensen and Curtis, 1976; Randolph *et al.*, 1981; Hsia, 1984; Kornegay and Notter, 1984; Spicer and Aherne, 1987; Nielsen *et al.*, 1995b; Mikesell and Kephart, 1999; Schmolke, 2000). However, there has been no research conducted on the effect of group sizes greater than 200 pigs on the social behaviour and growth performance of growing pigs.

Conventional thinking has been that smaller groups of pigs are able to form stable dominance hierarchies. It was thought that pigs kept in larger groups would have an unstable dominance hierarchy, as individual animal recognition may decline, and in turn outbreaks of aggressive behaviour, may affect growth performance and pig welfare. Little is known about the maximum number of pigs which are able to form a stable dominance hierarchy. Fraser and Broom (1998) suggested that the total number of group members that can be recognised by an individual is 20 to 30 in pigs.
Craig and Guhl (1969) studied hens in flocks of 100 to 400 birds. Hens in the larger groups tended to remain in particular areas of the shed and appeared to be "territorial" in areas where they spent most of their time. The authors suggested that social recognition would be easier for the hens if they remained in a particular area of the shed, and associated with the same individuals daily. It would appear beneficial for animals to remain in smaller groups within a larger group, as excessive aggressive behaviour would be prevented (Craig, 1981).

Recent experiments conducted on laying hens and broiler chickens have shown that aggressive behaviour declines as group size increases (Pagel and Dawkins, 1997; Hughes et al., 1997; Estevez, 1998; Nicol et al., 1999). These authors have several suggestions to explain this finding. For example, that the greater availability of resources, such as total free space, availability of feeding places and preferred lying areas, may eliminate the need for a dominance hierarchy, which functions to control aggression when resources are limited. Furthermore, the animals may be more socially tolerant in large groups or animals may abandon all attempts to establish social hierarchies in large groups.

However, other experiments conducted on laying hens (Bilcik and Keeling, 2000) have shown that most feather pecking activity and also the most aggressive attacks occurred in the largest group of hens. Fraser and Rushen (1987) reviewed the literature on aggression in pigs and stated that increases in group size and a reduction in floor space are associated with a higher incidence of aggression. However, the majority of experiments on pigs have studied group sizes of 60 or less. Petherick and Blackshaw (1987) concluded that larger groups of pigs have a higher level of general activity and social tactile interactions with each other, which results in an increase in agonistic behaviours, resulting in reduced growth performance. These results are similar to those of Bryant and Ewbank (1972), Randolph et al. (1981) and Hsia (1984). Spoolder et al. (1999) studied groups 20, 40 and 80 pigs per pen, and found that larger groups of pigs had significantly more skin lesions, which was explained by increased aggression.
Spoolder et al. (1999) concluded that in larger groups individuals are more likely to encounter other pigs that they do not recognize or with which they have to reconfirm their relative rankings, resulting in more carcass bruising. However, these experiments were conducted in pens without deep-litter or straw. The authors suggested that perhaps social tactile interactions would be less if straw was present, as the provision of straw has been suggested to reduce social tactile interactions (Fraser et al., 1991). Al-Rawi and Craig (1975) hypothesised that group size is positively correlated with a failure to resolve rank disputes without aggression, as the animals cannot recognise each other in large groups. This may result in an increase in social stress and may ultimately affect growth performance (Spoolder et al., 1999).

Some researchers have found that an increase in group size does not adversely affect growth performance when pigs are given ample space and the opportunity for ad libitum feed (Randolph et al., 1981; Kornegay and Notter, 1984; McConnell et al., 1987). In larger groups, poor availability of feed and other resources such as pen space may affect the growth performance of the pig.

The influence of larger group sizes on the growth performance of growing pigs is unclear. The majority of behavioural studies conducted on large groups of 200 or more animals have been conducted on hens, while the group size studies on pigs have been conducted on groups not exceeding 80 pigs. This thesis will examine the effects of large group sizes such as 200 to 1200 pigs on pig social behaviour and study the relationships between social behaviour and pig growth performance.

Space allowance

The recommended space allowance of pigs housed in conventional systems is 0.37 m² to 0.56 m² for growing pigs weighing 27 to 57 kg and 0.74 to 0.84 m² for finishing pigs weighing 105 to 125 kg (Ewing et al., 1999). The space allowance for growing pigs in deep-litter systems is 1 m² throughout the whole growing period (27 to 120 kg) (Payne, 1997).
It has been suggested that a greater space allowance is required in deep-litter systems for the maintenance of satisfactory pen conditions due to increased activity (Lyons et al., 1995), lack of clearly differentiated lying and excretory areas (Baxter, 1984) and infrequent removal of the deep-litter from the pen (Turner et al., 2000).

Reduced space allowance (crowding) affects the social behaviour and growth performance of pigs. The crowding that occurs in pig production generally consists of a decreased amount of space per pig and an increased number of pigs per group. Reduced space allowance can reduce pig performance (Ewbank and Bryant, 1972; Bryant and Ewbank, 1974; Kornegay and Notter, 1984; Gonyou, 1999b), presumably through stress and/or access to feed. The scientific literature suggests that reducing pen space allowance has a negative effect on the social behaviour of pigs. Abnormal behaviours such as tail biting, cannibalism and increased aggressive behaviours may occur when pen space is restricted (Jensen, 1971; Bryant and Ewbank, 1972; Randolph et al., 1981). Effective space is influenced by pen area, pen shape, floor type and arrangement and location of feeding and watering stations (Stricklin and Mench, 1987). Therefore, it is important to examine the effects of increased pen space allowance of pigs in deep-litter systems on their social behaviour and growth performance.

1.3.2 Physical environment

The physical environment has a significant effect of the growth performance of the pig. Some of the important components of the physical environment and their effects on social behaviour and growth performance will be reviewed here.

Litter

There is a plethora of information in the scientific literature in regards to the effects of deep-litter (environmental enrichment) on the social behaviour and growth performance of growing pigs (van Putten and Dammers, 1976; Wood-Gush and Vestergaard, 1989a,b; Schaefer et al., 1990; Beattie et al., 1995, 1996, 2000b; Peterson et al., 1995; O'Connell and Beattie, 1999). Small groups of pigs in conventional systems have however been used in these studies.
Foraging behaviour is a highly motivated behaviour in pigs (Wood-Gush and Vestergaard, 1989 a, b). Interactions with the physical pen, such as nosing pen fixtures and flooring, indicate that pigs are exploratory animals with an appreciable proportion of their time spent manipulating and examining their environment (Wood-Gush and Vestergaard, 1989 a, b; Stolba and Wood-Gush, 1989). Pigs are highly motivated to perform rooting behaviour and it is an obvious feature of ingestive behaviour. The pig’s snout is a highly developed sensory organ and olfactory cues play an important role in their behaviour (Fraser and Broom, 1998).

In unenriched environments, sometimes termed barren environments, pigs will tend to redirect this exploratory behaviour towards pen mates (Peterson et al., 1995), which may lead to tailbiting and cannibalism (Ewbank, 1973; Beattie et al., 1995; Fraser and Broom, 1998).

The effects of deep-litter on the social behaviour and growth performance of pigs are complex. Deep-litter may have three effects on the behaviour of pigs: (i) as a bedding, thermal comfort and physical comfort of the floor are improved, (ii) may result in a feeling of satiety if eaten (increase in gut fill and hind gut fermentation) and (iii) may serve a “recreational” function as a stimulus and outlet for rooting behaviour (Fraser, 1975; Fraser et al., 1991). Environmental temperature may affect the pig’s use of deep-litter. For instance, growing pigs prefer to lie on straw when environmental temperatures are low, but prefer bare floors when the temperatures are high (Fraser, 1985).

The effect of deep-litter on gut fill is of questionable benefit. Growing pigs are usually fed ad libitum and, if given adequate feeder access, should have a feeling of satiety throughout their growing period. Therefore growing pigs should not consume the deep litter as a feed source. However, the recreational effect of the straw may provide a potential benefit to growing pigs. Morgan et al. (1998) examined the influence of straw bedding on the social behaviour and performance of young pigs kept in groups, with the provision of kennels. The pigs on straw spent a greater period of the observation time standing and interacting with other pigs compared to pigs without straw bedding.
There was also an increase in aggressive behaviours in pigs on straw. It was suggested by the authors that there was an increase in aggressive encounters because the pigs were more active and were outside the confines of the kennel for a longer period of time.

On the other hand, Beattie et al. (1996, 2000a) showed that enriching the environment with the provision of straw reduced harmful social behaviours, such as persistent nosing of pen mates and tail biting, while increasing exploratory behaviours. Fraser et al. (1991) and Arey and Franklin (1995) also found that pigs on straw were more active and had a greater diversity of behaviours than pigs kept without bedding.

Aggressive behaviours which occur as a result of mixing unfamiliar pigs have been reduced by mixing pigs in pens with a deep bed of straw (Ewbank, 1969). Straw has also been shown to reduce aggressive behaviours between unfamiliar feed-restricted pigs (Kelley et al., 1980) and pigs fed ad libitum (Meyer et al., 1984). In contrast, Waran and Broom (1993) and Arey and Franklin (1995) observed no difference in aggressive behaviours in weaned pigs with or without deep-litter. Thus while the results are somewhat contradictory, research suggests that the provision of straw may reduce aggression and other harmful behaviours. Studies conducted on this topic have involved a range of conditions such as pig age, group size and indoor and outdoor systems.

Studies on the effect of environmental enrichment on pig growth performance have produced conflicting results. Schaefer et al. (1990), Horrell (1992), Guy et al. (1994) and Beattie et al. (2000b) showed that provision of novel objects improved growth rate, although feed intakes and backfat were increased. On the other hand, Pearce and Paterson (1993) and Blackshaw et al. (1997) found no improvement in pig growth performance when similar novel objects were provided.
The provision of deep-litter bedding may assist in reducing aggression in large groups of pigs as the pigs may direct their behaviour to the deep litter rather than pen mates. Research on the effects of deep-litter on the social behaviour and growth performance of pigs in large groups is clearly required.

1.4 The social behaviour of pigs in large groups in deep-litter, group housing systems

This literature review has identified that little is known of the social behaviour of pigs in large groups in deep-litter systems. Aggressive behaviours may be higher in larger groups of pigs, as individual animal recognition may not be functional. On the other hand, aggression may be reduced due to the deep-litter, environmental enrichment, which may stimulate pigs to redirect behaviours away from pen mates to the deep-litter. Furthermore the greater availability of resources in these large groups may reduce the need for aggression, or the pigs may be socially tolerant in these large groups.

The social behaviours of pigs in conventional systems with small group sizes have been clearly demonstrated in the scientific literature, however the social behaviour of pigs in deep-litter systems has not been extensively studied. Factors that may affect the social behaviour and performance of pigs in deep-litter systems, such as the provision of litter, increased group sizes and space allowance, require attention. The social behaviour of housing pigs in large groups on deep-litter and its implications for pig growth performance require rigorous investigation. This is the topic of this thesis.
2. THE FEEDING BEHAVIOUR OF PIGS

The feeding behaviour of pigs involves a complex series of decisions and is dependent upon mental, motor and digestive abilities (Fraser and Broom, 1998). Pigs are omnivorous, and in the wild they will consume vegetable material and small animals such as earthworms or other larger dead animals. Free-range pigs spend 6 to 7 hours per day searching for food. In contrast, domesticated pigs housed in conventional systems are fed concentrated diets and may only feed for 10 to 15 minutes per day (Hafez, 1975). Growing pigs normally consume between 10 and 20 meals per day (Gonyou, 1999a). The quantity of food that a pig will consume is affected by the palatability of the feedstuff. Pigs prefer feed with some sugar content, and constituents such as fish meal, yeast, wheat and soybean (Fraser and Broom, 1998). Palatability and thus intake is reduced when ingredients such as salt, fat, meat meal and cellulose are added to the diet. Hulling increases the palatability of cereals. Feed intakes are generally higher with wet foodstuffs, although this is dependent on palatability of the feed (Fraser and Broom, 1998).

Pigs showed a preferential diurnal feeding pattern (Feddes et al., 1989; Young and Lawrence, 1994). The pattern of daily feed intake in pigs can usually be characterized by two peaks; a relatively smaller peak in the morning with a large peak in the afternoon (Schouten, 1986; de Haer and Merks, 1992). The level of feeding throughout the day is intermediate compared to the peaks and night-time levels. If pigs are raised under continuous light the feeding pattern is less distinct with only a minor increase during the daytime period (Gonyou, 1999a). However, sometimes the feeding behaviour of pigs in modern conventional systems is influenced by management systems. Hand-fed pigs will move to the feeding area immediately before the stockperson is due to enter the room, and will often start feeding when stockpeople start work in the building (de Haer and Merks, 1992). Growing pigs in deep-litter systems are usually fed ad libitum, and normally have minimum disturbance from stockpeople due to the extensive nature of the system. Therefore feeding behaviour of pigs in deep-litter systems is unlikely to be influenced by management systems.
Social influences on feeding behaviour involve social facilitation and competition at feeding. Social facilitation is a common feature in the feeding behaviour of pigs. Social facilitation is an increase in behaviour in synchrony with other pigs engaging in the behaviour, such as an increase in feeding behaviour in the presence of others feeding. Feeding behaviour is often stimulated by the sight of other pigs feeding (Hsia and Wood-Gush, 1983). Social facilitation among pigs may increase the competition between pigs at feeding.

Feed resources can be restricted to varying degrees by dominant pigs in the group. Design of adequate feeding systems such as adequate feeder space and operational characteristics is essential (Ewing et al., 1999). Competition can be reduced by giving groups of pigs access to several feeders at one time (Hansen et al., 1982). Rooting is a salient feature of digestive behaviour in pigs (Fraser and Broom, 1998), and therefore feeding equipment for self-feeding is designed around the rooting habits of pigs.

Controlling feed intake is a major component in management of pork production systems. Feed cost can equate to 70 percent of total production costs, and therefore the feeding program should meet the nutritional requirements of the pig, without feed wastage (Ewing et al., 1999). Growth performance factors such as fat and protein deposition, may be influenced by feeding behaviour characteristics such as frequency of feed intake and meal size (Cohn et al., 1962; Foster et al., 1983).

In attempting to understand the feeding behaviour of pigs in deep-litter systems and its affects on growth performance, it is important to consider the effects of the social and physical environment of these systems.
2.1 Factors affecting the feeding behaviour and implications for growth performance

2.1.1 Social factors

The social environment has a significant effect on the growth performance of the pig and some of the important features of the social environment in relation to feeding behaviour will be reviewed.

*Individual vs group housing*

There is a significant difference in the feeding behaviour of growing pigs housed individually and in groups (de Haer, 1992; de Haer and Merks, 1992; de Haer and de Vries, 1993a). De Haer and de Vries (1993a) studied the pattern of feed intake of pigs housed individually and in groups and found that individually housed pigs had more frequent (73 vs 16 visits per day) but shorter visits (1.4 min vs 4.8 min) to the feeder compared to group housed pigs. Most feeding activity occurred during the day for both individual and group housing systems, although the diurnal feeding pattern of the individually housed pigs was more equally distributed across the day, compared to two peaks of activity: a relatively small peak in the morning followed by a large peak of feeding activity in the afternoon occurred in the group housed pigs (de Haer and de Vries 1993a; Labroue et al., 1994; Nielsen et al., 1995a,b; Morgan et al., 1998).

Social effects in groups may be responsible for the differences in feeding patterns between individually and group housed pigs. Factors such as social facilitation, competition at the feeder and social stress may be factors responsible for these differences in feeding behaviour (Bornett et al., 2000). Social facilitation may stimulate pigs in groups to feed simultaneously (Hsia and Wood-Gush, 1983), which may lead to increased competition for feeder space. Social effects within the group may also prohibit pigs from feeding at a preferred time. McBride et al. (1964), Hansen et al. (1982), Baxter (1983) and de Haer and Merks (1992) have all suggested that an increase level of social tactile interaction in a group of pigs may be responsible for longer but less frequent feeding bouts observed.
The feeding pattern of individually housed pigs may be due to lack of competition and stimulation to eat food (de Haer and Merks, 1992). Nielsen et al. (1995a) also suggested that the feeding pattern expressed by individually housed pigs may be the preferred pattern, and the variation observed in the feeding behaviour of grouped pigs may be an adaptation to the constraints placed on their feeding behaviour, such as variation in competition and social interactions. Differences in feeding behaviour of pigs between individual and group housing systems may be also be influenced by differences in the feeding system.

There have been few reports in the literature of experiments where the two housing regimes have been imposed on the same pigs. Nielsen et al. (1996) found that pigs moved from group housing to individual housing made only small modifications to their feeding behaviour, indicating that their feeding patterns were inflexible. However the pigs in the experiment were not housed individually before grouping, so their 'preferred' feeding pattern may have been less well defined (Bornett et al., 2000). Bornett et al. (2000) studied the feeding behaviour of pigs that were individually housed from weaning and then mixed into groups. Feeding behaviour was affected by grouping resulting in longer, less frequent feeding bouts in the group housed pigs.

Individually housed pigs have improved growth performance compared to group housed pigs. They have a higher average daily intake, a higher growth rate, are fatter and have a more efficient feed conversion compared to group-housed pigs (Spicer and Aherne, 1987; Gonyou et al., 1992; Chapple, 1993; de Haer and de Vries, 1993a; Nielsen et al., 1996). These differences in growth performance may be related to the pattern of feeding. Fat deposition and lean tissue growth, through the utilisation of nutrients in the diet, are affected by food intake and meal size (Cohn et al., 1962; Batterham and Bayley, 1989). Cohn et al. (1962) found that the ingestion of full-spaced meals (meal eating) compared to frequent small meals (nibbling) increased body fat, decreased body protein and water, increased urinary nitrogen excretion and resulted in a higher feed to gain ratio. Foster et al. (1983) found that pigs expended less energy on feeding behaviour when they ate fewer larger meals and were thus energetically more efficient.
The frequency of feeding may also influence lipase and amylase secretions (Hee et al., 1988) and the pattern of mobility of the small intestine (Ruckebusch and Bueno, 1976), which affects the efficiency of feed use for protein deposition.

Quinioiu et al. (1999) studied the effect of feeding behaviour on the performance of individually housed Pietrain and Mieszan growing pigs. Differences in pig growth performance was influenced by feeding behaviour. Lean Pietrain pigs had a high frequency of small meals throughout the day while fat Mieszan pigs had a small number of larger meals. The authors hypothesised that a higher propensity of fat deposition is associated with a reduced number of meals, whereas smaller meals eaten more frequently may favour protein deposition. This may also explain the higher growth rate observed in individually housed pigs as they have a smaller but more frequent meals than group housed pigs.

De Haer and Merks (1992) indicated that the high daily gain and increased fatness of individually housed pigs may result from a low level of activity (elimination of social interactions), or a higher digestibility coefficient due to smaller more frequent meals. Patterson (1985) concluded that less metabolic heat was produced by individually housed pigs compared to group housed pigs, resulting in an increase in growth rate and fat deposition in the former group of pigs. In addition, Patterson (1985) also concluded that individually housed pigs may have increased corticosteroid hormones (as a result of a chronic stress response due to inadequate social contact with other pigs), which may lower nitrogen retention by increased protein catabolism, thus increasing carcass fat deposition.

This review has demonstrated that we have a clear understanding of the feeding behaviour of pigs housed individually and in conventionally-sized groups, however there is a deficiency in the literature on the feeding behaviour of pigs in larger groups of pigs. An increase in social tactile interactions is thought to influence the feeding behaviour of pigs in groups. This thesis will study the feeding behaviour of pigs in deep-litter systems, which will provide an understanding of the feeding behaviour of large groups of pigs.
Dominance hierarchy

Differences in feeding behaviour of pigs in groups may be a reflection of social hierarchy (Morgan et al., 1999), which in turn may affect growth performance. A number of experiments have reported a positive correlation between dominance rank and growth performance (McBride et al., 1964; Beilharz and Cox, 1967; Hansen et al., 1982; Vargas Vargas et al., 1987). The effect is more severe when access to resources such as feed is limited. Hansen et al. (1982) found that social rank affected average daily gain only when one feeder was available in the pen. Vargas Vargas et al. (1987) found similar results in an experiment studying the effects of feeding systems on feeding behaviour and growth performance of finishing pigs. These authors found feeding behaviour, aggression and social rank were associated with average daily gain in feed restricted systems. The more aggressive pigs had more feeding bouts and displaced other pigs from the feeder, which gave them the opportunity to have a higher average daily gain. These changes in feeding behaviour were not seen in the ad libitum feeding system, which confirm results found by Hansen et al. (1982). Nielsen et al. (1995a) found no correlation between aggression and position in the dominance hierarchy on feeding behaviour or growth performance when the pigs had high space allowance, and ad libitum feed and were provided with straw.

Therefore, the influence of dominance hierarchy on feeding behaviour and growth performance of group housed pigs is likely to depend on aspects of the feeding system such as feeder design and ad libitum feeding which affect the pigs access to feed.

Group size

As previously discussed, a large number of experiments have been conducted on the effect of group size on pig growth performance (Jensen and Curtis, 1976; Randolph et al., 1981; Hsia, 1984; Kornegay and Notter, 1984; Spicer and Aherne, 1987; McGlone and Newby, 1994; Nielsen et al., 1995; Mikesell and Kephart, 1999; Schmolke, 2000).
However, there has been no research conducted on the effect of group sizes greater than 200 pigs on the feeding behaviour and growth performance of growing pigs. Walker (1991) studied the feeding behaviour and performance of growing pigs in groups of 10, 20 and 30 pigs using single space feeders. He found that groups of 20 and 30 had poorer feed conversion efficiency, and the number of pigs queuing to feed at hourly intervals was greater in the larger groups. Nielsen et al. (1995) compared the feeding behaviour of pigs housed in groups of 5, 10, 15 and 20. Feed intake was similar in both group sizes, but pigs in groups of 20 ate less frequently, quicker and in more synchrony than pigs in the smaller groups. This indicates that as the number of pigs increase in the group, feeding behaviour changes in order to achieve the desired level of food intake. These studies suggest that as group size increases the number of feeding bouts decreases and the duration of feeding increases. This theory requires further investigation and will be examined in this thesis.

Space allowance
Reduced space allowance (crowding) has been shown to affect the growth performance of pigs (Ewbank and Bryant, 1972; Bryant and Ewbank, 1974; Kornegay and Notter, 1984; Gonyou, 1999b). Black et al. (1995) concluded that feed intake is depressed once the floor space allowance falls below 0.035-0.039 m² LW^{-0.67} where LW is live weight (kg). In addition to social stress, reduced space allowance in the pen may affect the pig's access to the feeder and in turn feeding behaviour. Gonyou (1999a) suggested that reduced feed intake was not due to poor accessibility to the feeder, but due to reduced appetite. However, the effects of pen space on feeding behaviour have not been examined extensively.
2.1.2 Physical environment

The physical environment has a significant effect on the feeding behaviour and growth performance of the pig and some of the important features of the physical environment in relation to feeding behaviour will be reviewed here.

*Feeding system: feeder design, feed type and feeder layout*

The feeding system, design of the feeders and feeder layout all have the potential to influence feeding behaviour and growth performance of pigs. Most modern pork production systems use *ad libitum* feeding as a practical method of feeding pigs. Programmed, time-feeding systems are also available and offer an alternative to the traditional method of feeding (Vargas Vargas et al., 1987). The feeding behaviour of pigs is influenced by the type of system used to feed the pigs. Vargas Vargas et al. (1987) studied the feeding behaviour and growth performance of growing pigs under these two systems. The results indicated that in time-restricted feeding the more aggressive and more dominant pigs visited the feeder earlier and more frequently, displaced more pigs and had a higher growth rate than the pigs in the *ad libitum* feeding system. The authors suggested that time-restricted feeding systems should be designed to reduce adverse consequences of competition for less aggressive and lower ranking pigs. Restrictively fed pigs spend more time standing (Graves et al., 1978), had more harmful social tactile interactions (Robert et al., 1991) and spend less time lying (Day et al., 1995) than pigs fed *ad libitum*.

Traditionally the recommendation for feeding places was five pigs per feeder space (Gonyou, 1999a). This resulted in feed wastage, as feeder design was not considered. Currently, feeders are designed to provide protection for the pig, reduce aggression and to enable maximum feed intake. If a pig is protected from other pigs, it will eat quicker due to easier access to food and less interference from other pigs and as a consequence more pigs can be fed from the one space. It is not uncommon to see the provision of one feeder space for each 10 to 15 pigs (Gonyou, 1999a).
Single-space feeders have a number of advantages compared to conventional multi-space feeders. For example, single-space feeders protect the pig’s head and shoulders whilst feeding. Furthermore, because water is supplied in the feeder, the need for the pig to move away from the feeder during eating is reduced (Hutson, 1995).

Nielsen et al. (1996) studied the feeding behaviour and performance of pigs with access to either single or multi-space feeders. Pigs were kept in groups of ten, and thus the effects of social environment, over and above those imposed by the pig:trough ratio, were similar for both treatments. This experiment showed that multi-spaced feeders reduced the competition for feed and allowed the animals to feed more freely, in a pattern similar to the feeding behaviour of individually housed pigs. These results suggest that the difference in feeding behaviour between individually and group-housed pigs may be a consequence of the number of feeding spaces available.

Wet/dry feeders have been developed to provide the pig with the option of eating the feed wet or dry. Gonyou (1999a) studied the feeding behaviour and growth performance of pigs with access to wet/dry feeders or dry feeders. Pigs spent less time feeding from wet/dry feeders than from dry feeders. There was also less activity at the wet/dry feeders as the pigs remained in the feeding area once they entered. Feed intake and average daily gain were increased by 5 percent using wet/dry feeders. Water use was also reduced by 30 to 40 percent in wet/dry feeders.

Grinding (meal) and pelleting are the most common processing methods used for pigs (Pond et al., 1995). Pellets are reported to reduce feed wastage (Pond et al., 1995; Hutson, 1997) and it has been shown that pigs prefer pellets to meal of the same diet formulation (Krider and Carroll, 1971; Skoch et al., 1983; Pond et al., 1995).
The layout of feeders in pens housing large groups of pigs on deep-litter needs to be considered. The distance that a pig has to travel to feed should be minimised to reduce social pressure associated with feeding. Gonyou (1999a) suggests that feeders should be placed in the centre of the pen, to minimise distance to feed and allow the pigs to use the perimeter of the shed for lying and dunging. Often pigs housed in deep-litter systems are required to travel large distances to feed compared to pigs in conventional housing systems. This extra effort required to feed may also influence the feeding behaviour and growth performance of pigs in deep-litter systems and requires further investigation.

**Thermal environment**

The conditions in which a pig is housed influences the thermal environment. Voluntary feed intake of individually housed pigs in an environment where the pig is in the zone of thermal comfort is closely related to the capacity to utilize nutrients. Voluntary feed intake increases once the ambient temperature falls below the lower critical temperature and the energy expenditure of the pig increases. Conversely, feed intake declines at temperatures above the evaporative critical temperature (Black et al., 1999).

Group housing may influence the micro thermal environment and feeding behaviour as an individual within a group may be unable to lose body heat because of the close proximity of other pigs. This increase in heat may result in a reduction in food intake. On the other hand, if it is cold an individually housed pig will eat more, whereas group-housed pigs will huddle together to conserve heat and will ultimately require less food than the individually housed pig. In both hot or cold conditions, group housing may reduce food intake (Morgan et al., 1999). The feeding regime influences the effects of climate on protein and fat deposition. Under restrictive feeding systems, pigs exposed to the cold become leaner (Verstegen et al., 1987).
It is unlikely that the observed differences in the feeding behaviour and performance of individually and group housed pigs can be explained solely by differences in thermal environments. De Haer and Merks (1992) compared the feeding behaviour and performance of pigs in individual and group housing systems in the same thermal environment. The observed lower feed intake of the group housed pigs cannot be explained by thermal differences. The thermal environment may be only one of the factors explaining why group-housed pigs eat less than individually housed pigs (Morgan et al., 1999).

Litter

Various experiments have been conducted to measure the growth performance of pigs with litter provided, although the results have often been contradictory. Lyons et al. (1995) studied the growth performance and welfare of growing pigs with or without straw bedding. Pigs in the deep-litter straw grew significantly faster and had higher feed intakes than pigs without straw. This increased growth performance of the deep-litter pigs was interpreted by the authors to be due to an increase in activity of the pigs. For example, an increase in activity may lead to increased awareness and exploitation of vacant feeders, however this was not confirmed by the time spent at the feeder. Similarly, Morgan et al. (1998) examined the influence of straw bedding on feeding behaviour and growth performance of pigs kept in groups. Pigs on straw showed an increase in the number of visits to the feeder, showed a shorter average duration of visits and consumed less feed per visit than pigs without straw bedding. However, the daily food intake and feeder occupation was the same for both treatments. Morgan et al. (1998) suggested that there was no obvious explanation for the increase in number of visits to the feeder, although it was suggested that the increase in activity and exploration caused the greater number of visits to the feeder.
Beattie et al. (2000b) compared the growth performance of pigs reared on slatted floors with the minimum space allowance to pigs reared with extra pen space with straw and peat provided. The feed intake, growth rate and back fat were higher in pigs raised with extra space and litter. This change in growth performance was explained by changes in the feeding behaviour. High levels of harmful social behaviours in the barren environment were thought to have disturbed the feeding pattern, resulting in reduced feed intake, growth rate and backfat.

The influence of deep-litter on the feeding behaviour and growth performance of pigs in groups requires further investigation.

2.2 The feeding behaviour of pigs in deep-litter, group housing systems

As previously mentioned pigs housed in groups consume less food and have a lower growth rate and are leaner compared to pigs housed individually (Gonyou et al., 1992; Chapple, 1993; de Haer and de Vries, 1993a; Nielsen et al., 1996). Both social and physical factors may affect the feeding behaviour of pigs in deep-litter, group housing systems. Spoolder et al. (1999) suggested that the increase in social pressure in larger groups of pigs may increase competition for available resources. The authors suggested that even though theoretically the ratio of feeders to pigs is the same for smaller and larger groups of pigs, there may be more competition in larger groups of pigs. For example, social facilitation (Hsia and Wood-Gush, 1983) may encourage large groups of pigs to want to feed at the same time. Secondly, dominant pigs may control the feeders and prohibit their subordinates access to the feeder and finally pigs may have preferred feeding spaces. If this were the case, these three factors would increase the competition for feeding in large groups of pigs and could influence feeding behaviour, and ultimately growth performance.

Animals make adjustments to their feeding behaviour as more effort is required to feed. For example, as it becomes harder to obtain feed, the frequency of feeding may decline. Food intake may remain the same because compensatory increases occur in the size of the meal. Animals foraging in the natural environment visit fewer patches, but stay longer in each patch as a function of increasing travel time between patches (Johnson and Collier, 1994). Pigs housed in deep-litter systems
are required to travel further to feed compared to conventionally housed pigs. Thus more effort may be required for deep-litter, group-housed pigs to obtain feed, which may influence their feeding behaviour in that feeding frequency may decline and in turn affect growth performance.

 Provision of litter in the deep-litter systems may influence the feeding behaviour of growing pigs. Increased activity and exploratory behaviour as a result of the enriched environment may stimulate more frequent feeding bouts as the vacant feeder is noticed and exploited more frequently. Furthermore, reduced social tactile interactions with pen mates in the enriched environment may provide the opportunity for increased feeder accessibility, resulting in increased feed intakes, growth rate and backfat.

 In conclusion, as with the scientific knowledge on social behaviour, the literature on the feeding behaviour of pigs housed in large groups housed on deep-litter is poor. In addition to examining social behaviour, this thesis will also study the feeding behaviour of pigs in deep-litter systems. The implications of feeding and social behaviour on growth performance will be considered.
3. STRESS PHYSIOLOGY

The previous sections of this literature review have examined the influence of social and feeding behaviour on the growth performance of pigs in deep-litter housing systems. Stress may be another factor that influences the growth performance of pigs in deep-litter systems, as pigs are often housed in large groups greater than 200 pigs. These large group sizes may inhibit individual animal recognition and produce an unstable social hierarchy, which may result in social stressors. In order to understand the effects of stress on growth performance of pigs in deep-litter systems, it is necessary to define the stress response and methods used to objectively measure stress. The stress response and the effects of stress on pig growth performance will also be reviewed in the following sections.

3.1 A definition of stress

Stress is a difficult term to define, because unlike a disease, stress has no specific aetiology or outcome. Individual animals differ in the way that they respond to the same stressful situations (Moberg, 1993). Several definitions of stress have been presented in the literature, but a useful one is the following:

"Stress is the biological response to an event that the individual perceives as a threat to its homeostasis. That event which is perceived as a threat is defined as the stressor" (Moberg, 1993).

Homeostasis refers to the maintenance of a body variable in a steady state by means of physiological or behavioural regulatory actions (Fraser and Broom, 1998). Therefore stress involves both a disruption of homeostasis and the process initiated to re-establish homeostasis (Hemsworth and Coleman, 1998). Selye (1946) observed a general nonspecific biological response when animals were subjected to a number of stressors, which he eventually defined as the general adaptation syndrome (GAS). The first stage of the GAS is the activation of the hypothalamo-pituitary adrenal axis. The second stage consists of the animal physiologically coping with the stressor (resistance stage) and finally the third stage refers to the animal no longer coping and adapting to the challenge of the stressor.
A stressor is the stimulus that causes disruption of homeostasis and it can be physical, psychological or physiological (Dobson and Smith, 1995). Stressors in animal production include crowding, weaning, mixing unfamiliar animals, transportation, dehorning, tail docking and unfamiliar environments (Moberg and Wood, 1982; Carter et al., 1983; Tarrant, 1990; Lay et al., 1992; Dobson and Smith, 1995).

3.2 The stress response

The stress response is the process whereby the animal alters behaviour and physiological functions in order to maintain homeostasis. There are a series of biological responses that are available to the animal once a stressor is perceived. These responses are behavioural, autonomic and neuroendocrine. Animals have evolved these biological responses to enable them to ensure that they have the best chance of survival in the wild (Moberg, 1993).

The behavioural response is the most effective mechanism that the animal has in coping with stressors. For instance, if there is insufficient space for the animal, it may simply remove itself from the location or situation. However, behavioural responses may not be appropriate or effective for all situations (Moberg and Mench, 2000). For example, in animal production, the behavioural response may be insufficient since confinement may restrict the behaviours necessary to cope with the situation (Moberg, 1993). Nevertheless, Hemsworth and Barnett (2001) concluded that some component of behaviour is likely to be involved in every stress response.

In addition to the behavioural responses, the physiological responses that are used by the animal when faced with a stressor are elicited in three series of events, with the full elicitation of these physiological responses dependent on the time that the animal is exposed to the stressor and the success of the biological responses in coping with the challenge (Hemsworth and Coleman, 1998). The first of these biological responses is the autonomic response, which is often referred to as the response of the sympathetic adrenal medulla (SAM) axis.
When an animal is exposed to a stressful situation, a primary "fight-flight" reaction occurs (Metveit, 1984) and the SAM axis is activated. This response may include escape or avoidance responses and the secretion of catecholamines such as adrenaline (epinephrine) released from the adrenal medulla and noradrenaline (norepinephrine) released from the adrenal medulla and the nerve endings from the sympathetic nervous system (Hemsworth and Barnett, 2001). As a consequence, further physiological responses occur such as an increase in the heart rate, higher blood pressure, contraction of the stomach and sphincters, suppression of intestinal movements and activity, glandular stimulation and glycogenolysis (Moberg, 1985; Bone, 1988; Sapolsky, 1992).

Glycogenolysis, the utilization of muscle and liver glycogen provides an energy source for the animal (glucose) and prepares the animal to react quickly to a threatening situation (Metveit, 1984). The catecholamines have a half-life of only several minutes (Broom and Johnson, 2000). This initial reaction to the stressor is short-lived and if the stressor is not removed a second series of physiological reactions occurs (Hemsworth and Barnett, 2001).

This second series of physiological reactions involve the stimulation of the hypothalmo-pituitary adrenal (HPA) axis. The second series is often called an acute stress response and is part of the GAS and is a corticosteroid-dependent mechanism. The first stage of the response of the HPA axis is the release of corticotrophin-releasing factor (CRF) from the hypothalamus via interleukin 1B (Sapolsky, 1992; Broom and Johnson, 2000). This results in the release of adrenocorticotropic hormone (ACTH) from the adenohypophysis (anterior pituitary). There are various hormones that modulate the release of ACTH, such as arginine vasopressin (AVP) and oxytocin (Sapolsky, 1992). ACTH is released into circulation within 2 to 5 minutes of a stressor and reaches peak concentrations 5 to 20 minutes after stimulation (Clarke et al., 1997).
ACTH is transported to the adrenal cortex via the blood and stimulates the secretions of cortisol and corticosterone. These glucocorticoids promote gluconeogenesis, the conversion of protein to carbohydrates (glucose or glycogen) which is used as an energy source for the increase in metabolic requirements. Therefore, during this stage homeostasis is achieved in which the increased demand for energy is met by increased metabolic performance. This physiological state of stress generally disappears when the stress is removed and has no major effects on the welfare of the animal other than depletion of energy reserves. There are some situations when an acute stress response could have detrimental effects on animal production. These include effects on meat quality (Moss, 1984) and reproduction (Moberg, 1985; Clarke et al., 1992) and will be discussed later in this review. The acute stress response is effective in allowing the animal to adapt to changes in its environment (Hemsworth and Barnett, 2001).

A third series of physiological events occur if the stressor continues and this response is the chronic stress response (Selye, 1976). This is corticosteroid dependent and comes at a physiological cost to the animal. Prolonged elevated concentrations of corticosteroids affect reproduction (Clarke et al., 1992; Moberg and Mench, 2000), immune function (Blecha et al., 1984) metabolism and growth performance (Elsasser et al., 2000). Therefore, abnormal function of these systems is an indication of a welfare problem with the particular animal (Moberg, 1993).

The measurement of the activity of the SAM and HPA axes are amongst the most useful in the assessment of how difficult it is for the animal to cope with short-term problems. The activation of the HPA axis is also useful in assessing how the animal is coping with long-term problems. In order to assess the biological cost of stress (and to assess long-term problems), Moberg (1987) developed a model of animal stress. The stress response is considered in three main stages. The first stage involves the animal’s perception of a threat to homeostasis, the second involves the animal’s response and third involves the consequence for the animal.
Stress in the short-term (i.e. activation of the SAM and HPA axes) has only a minor biological cost to the animal. However, a chronic stress response (i.e. a prolonged activation of the HPA axis) results in significant change in biological function. It is at this stage when the animal enters the prepathological state and is vulnerable to infectious disease and depressions in growth and reproduction (Moberg, 1993).

### 3.3 The effects of stress on growth performance

If an animal perceives a threat to its homeostasis, regardless of whether a behavioural, autonomic or neuroendocrine biological response occurs, a change in biological function always occurs. This change in biological function may come at a cost to the animal. For example, a stress response diverts energy away from growth to provide the animal with the resources to cope with the stressor (Broom and Johnson, 2000).

Meat quality can be affected if the SAM response is substantially activated prior to slaughter. Muscle pH normally declines from slaughter until the onset of rigor mortis at about 6 to 8 hours later. However, rapid glycogenolysis under the influence of adrenergic mechanisms as a consequence of acute stressors imposed on pigs immediately prior to slaughter will increase muscle temperature, increase lactic acid concentration and increase rate of muscle pH decline post-slaughter (Moss, 1984), which in turn can lead to pale, soft and exudative (PSE) pork. PSE pork is considered unfavourable to the consumer (Broom and Johnson, 2000).

The activation of HPA axis generally has a much greater effect on animal performance. Glucocorticoids have numerous effects, one of which is the effect on metabolic processes. Glucocorticoids promote gluconeogenesis, the process of converting protein to carbohydrate (glucose or glycogen). Proteins are broken down into amino acids and are then deaminated. The glycogenic amino acids then enter the glycolysis scheme at the pyruvate stage of the tricarboxylic cycle. This enters the reverse reaction path of the glycolysis scheme and subsequently forms glucose or glycogen (Bone, 1988).
Fat is an important form of energy storage to the animal, principally because glycogen storage is slight and is saved for specific (e.g. muscle energy) purposes and is generally not available for general use. Fat is a highly concentrated energy form. A gram of fat contains 2.25 times the energy than a gram of glycogen (Bone, 1988). Noradrenaline and adrenaline act directly upon fat cells and increase fat mobilisation. ACTH probably functions through the stimulation of the adrenal cortex than directly on the fat cells (Bone, 1988).

Corticosteroids have been shown to increase plasma glucose and enhance liver gluconeogenesis in birds. The gluconeogenesis is from proteins and is shown by an increase in plasma non-protein nitrogen, and a decrease in the incorporation of glucose carbon into protein. Fat deposition results from a shift in the metabolism of the bird. There is a net synthesis of fatty acids and the ratio of saturated to unsaturated fatty acids increases (Siegel and van Kampen, 1984).

Experiments have shown that exogenous corticosterone administration or stimulation of the adrenal glands results in slower growth and an increase in food consumption in young birds. Siegel and van Kampen (1984) conducted an experiment to explain the apparent inefficiency in energy retention in growing chickens receiving corticosterone. The results confirmed previous reports that corticosteroids reduced weight gain despite increases in food consumption. Carcass data confirmed that protein deposition was reduced and fat deposition was increased. Similarly, corticosteroids administered to sheep and cattle increased fatness, although food intake was also increased (Forbes, 1995).

This discussion of the effects of activation of the SAM and HPA axis may be useful in understanding the implications of stress in pigs associated with maintaining social order, living in crowded conditions etc. Chapple (1993) suggested that cortisol secretion is implicated in the reduced performance of pigs housed in groups, although it is not the sole cause. For example, stressors can cause porcine somatotrophin and associated insulin-like growth factors to be down regulated.
Stressors such as crowding (Cunningham, 1982), physical trauma (Richards, 1980) and unpleasant handling (Hemsworth et al., 1981) have been shown to reduce growth rate in young animals and live weight in mature animals. Hemsworth and Barnett (1991) and Klasing (1985) have shown that stressors such as these, as a consequence of increased concentrations of corticosteroids can have effects on growth rate, independent of effects of feed consumed.

Reports of the extent to which the impact of stress on physiological processes such as growth performance, varies considerably in the scientific literature. Indeed, the literature is unclear and somewhat contradictory. Our understanding of the stress response, particularly the magnitude of the stress response, on growth performance is poor.

3.4 The welfare assessment of pigs

Deep-litter housing systems for growing pigs are perceived as being “welfare friendly”, as pigs have more room to move in an enriched environment. However there is limited scientific literature on the welfare of pigs in deep-litter, group housing systems. It is essential to review approaches to studying animal welfare before any objective assessment of animal welfare can be made. The assessment of welfare is a controversial subject within science. This controversy has risen because of variations in definitions of welfare, poor methodology and analysis of welfare experiments. It is essential to be very clear in terminology and definitions when studying animal welfare (Duncan and Fraser, 1997; Hemsworth and Coleman, 1998; Barnett et al., 2001).

There are four approaches used in studying animal welfare: functioning-based or homeostasis approach (Barnett et al., 2001), feelings-based approach, nature of the species approach and the animal-choices approach (Duncan and Fraser, 1997).
Functioning-based or homeostasis approach

The welfare of an animal is its state as regards to its attempts to cope with its environment (Broom, 1986). When animals are faced with conditions in which they cannot cope, their individual fitness may be reduced as a consequence of physiological and behavioural responses. Attempts to cope include the functioning of the body repair system, physiological stress responses, immunological defences and behavioural responses (Barnett et al., 2001). The welfare of the animal can therefore be assessed in a scientific way that is independent of moral considerations (Broom and Johnson, 2000).

Using the definition of Broom (1986), welfare risks can be studied at two levels: the behavioural and physiological responses of the animal to the challenge, and secondly the consequent biological cost to the animal (reduced biological fitness). The behavioural and physiological stress responses of the animal to the environment are the responses that the animal is using to return to homeostasis. Substantial and prolonged behavioural and physiological responses can have affects on biological fitness by affecting growth performance, reproduction, injury, health and survival (Hemsworth and Barnett, 2001; Broom and Johnson, 2000).

It should however be recognized that there are some limitations with this approach in assessing animal welfare. Our current knowledge may not allow detection of less serious risks to animal welfare, however more subtle risks to animal welfare should be reflected in changes in the biological fitness of the animal and the magnitude of the behavioural and physiological response (Hemsworth and Barnett, 2001; Barnett et al., 2001).

In utilizing this approach to welfare assessment, the following measures can be used:

Behavioural measures of welfare:
If an animal perceives a threat to its homeostasis it will change its behaviour accordingly. Behavioural measures are useful indicators of long-term problems for an animal (Broom and Johnson, 2000). The simplest of the behavioural measures is the measurement of problems with movement. For example, if the environment prohibits the animal from moving i.e. a slippery floor, the animal is lame or the
animal is closely confined. Behavioural measures such as locomotion, vocalization and avoidance have been used to measure acute stress in animals. Other short-term behavioural responses include orientation reactions, startle responses and defensive or flight reactions. Redirected behaviours and stereotypies are examples of the behavioural change that may be indicative of long-term welfare challenges. Pigs living in an environment without adequate environmental stimulation may develop aggressive behaviour and tail biting may occur (Fraser and Broom, 1998). These behaviours may be a consequence of a lack of resource, or some specific frustration. There is considerable diversity both within and between species in behavioural responses when animals are confronted with a stressor, however a feature of all these situations is the animal’s lack of control of its interactions with environment (Broom and Johnson, 2000).

Physiological measures of welfare:

*Heart rate:* Measurement of the heart rate is a useful measure of a short-term physiological response to a stressor, provided that the measurement itself does not cause too much disturbance to the animal. Handling by affecting movement increases the metabolic rate and will affect the heart rate of the animal (Broom and Johnson, 2000). The activation of the SAM axis increases the heart rate and the activation of the HPA axis decreases the heart rate (Broom and Johnson, 2000). Thus heart rate should not be used as the only measurement of the stress response.

*Blood pressure:* Measurement of blood pressure can be a useful indicator of long-term welfare problems. Blood pressure measurements must be carefully interpreted as the procedure can have an effect on the animal (Broom and Johnson, 2000).

*The adrenal axis:* Measurements of the SAM and HPA axes are amongst the most useful indicators of poor animal welfare (Broom and Johnson, 2000). It is difficult to measure changes in the SAM axis (catecholamines-adrenaline (epinephrine) and noradrenaline (norepinephrine)) due to rapid and varied responses (Moberg, 1987). Catecholamines may be a useful measure of the acute stress response (SAM) if they are sampled within one minute of exposure to the stressor in catheterized animals (Broom and Johnson, 2000).
The primary measurement of the stress response has been the measurement of adrenal corticosteroids (Moberg, 1987). These corticosteroids inhibit ACTH secretion, therefore it is difficult to measure ACTH as it is removed from the blood so quickly. Blood sampling may be used to measure activity of the SAM and HPA axes. Care must be taken as the procedure used to sample may evoke increased release of ACTH and corticosteroids. Concentrations of corticosteroids rise 2 minutes after the stress occurs, therefore blood sampled within a two-minute window via an indwelling catheter or via jugular venipuncture may be used (Broom and Johnson, 2000).

Alternative sources for cortisol assessment have been investigated and are briefly discussed. In saliva, cortisol exists in its free form and therefore reflects the biologically active, unbound fraction in cortisol (Fenske, 1997; Fell et al., 1985; Greenwood and Shutt, 1992). Salivary cortisol has been used as a measure of acute stress response in pigs by Parrott and Misson (1989), Parrott et al. (1989), Ruis et al. (1997), Bradshaw et al. (1998), de Jong et al. (1998) and Geeverink et al. (1999). In order to minimise the effect of handling and sampling on salivary cortisol, it is necessary to train animals to be accustomed to the procedure.

Faecal cortisol is an alternative to saliva and has been assessed in other species (Monfort et al., 1998; Goymann et al., 1999). In general, increases in faecal cortisol are apparent within 48 hours of exposure to a stressor. Concentrations of cortisol in faecal samples have been found to increase within 24 to 50 hours of exposure to a stressor such as an ACTH challenge (Monfort et al., 1998; Goymann et al., 1999). Faecal cortisol would therefore be indicative of a chronic and not an acute stress response.

Urinary corticosteroids have been assessed as an alternative to plasma corticosteroids in pigs by Hay and Mormede (1998). In urine, cortisol is found in its free form. The free cortisol from the plasma enters the urine via glomerular filtration of blood by the kidneys. The plasma cortisol thus accumulates in the urine so that the voided urine represents the average free cortisol circulating between urinations (Miller et al., 1991).
In order to use urine or faeces as alternatives to plasma cortisol, it is important to be able to determine the time over which the urine or faecal sample was produced and the frequency of urination and defecation, and to ensure that urine or faeces were the major routes of corticosteroid excretion (Lee and McDonald, 1985).

ACTH challenge
An ACTH challenge may be conducted to assess the adrenal function of the animal. If an animal is chronically stressed the adrenal gland is chronically hyperstimulated by ACTH. The adrenal gland under stress undergoes hyperplasia (increases in size and weight), and the capacity of the gland to secrete cortisol increases (Broom and Johnson, 2000). Adrenal gland responsiveness in pigs can be assessed on the basis of the cortisol response to an intramuscular injection of 50 IU ACTH. Blood samples taken 60 minutes after an ACTH injection were found to reflect maximal response by (Hennessy et al., 1986). An ACTH challenge is a useful measure of activation of the HPA axis in pigs and will be used as a measure of the stress response of pigs raised in deep-litter and conventional systems in this thesis.

The functioning-based or homeostasis approach offers scientists the best assessment of animal welfare with our current state of knowledge.

Feelings-based approach
The feelings based approach defines animal welfare in terms of emotions. Emotion is defined as psychological arousal (Dantzer, 2001). This approach assumes that animals are sentient creatures capable of pleasure and displeasure, instead of reactive organisms. Psychologists consider that emotions have several components, which include visceral or bodily responses, cognitive processes and the associated sensation of emotion (Duncan and Fraser, 1997). While each emotion may reflect a different pattern of arousal, the visceral or bodily response to many emotions is reasonably uniform in animals (Duncan and Fraser, 1997). The feelings-based approach to welfare assessment emphasises reduction in negative emotions such as pain and fear and increases in positive emotions such as joy and pleasure. Current research in psychology and neuroscience is establishing relationships between cognition and emotion, which may eventually enable measurement of emotion to become a measure of animal welfare.
Nature of the species approach

The principle underlying this approach to animal welfare assessment is that animal should be raised in "natural" environments and allowed to behave "naturally". This approach has led to the development of the five freedoms' requirement for animals.

"Five Freedoms" (UK Farm Animal Welfare Council, 1992):

- Freedom from hunger and thirst,
- Freedom from discomfort,
- Freedom from pain, injury and disease,
- Freedom to express normal behaviour,
- Freedom from fear and distress.

The full "repertoire" of an animal’s behaviour has been considered within this approach to assessing animal welfare (Fraser and Broom, 1998). There are however are number of limitations with the nature of the species approach. The nature of the species approach fails to define both "natural" and the welfare risks if such "natural" conditions are not provided. Furthermore, "natural" behaviour often depicted as "wild" behaviour which represents an animals attempt to survive in the wild, with somewhat aversive conditions throughout their life. Therefore, situations which could adversely affect the welfare of an animal, should be eliminated in domestic production situations. For example, piglet mortality often exceeds 25 percent in the wild boar (Sus scrofa), which would obviously be unacceptable in commercial production systems (Broom and Johnson, 2000).

Modern domestic animals are the product of thousands of years of selective breeding, and as a consequence the behaviour and physiology of domestic animals is somewhat different to that of animals in "wild" or "natural" conditions. Whilst the behaviour of domesticated animals may be similar to their "wild" relatives, there are differences in their behavioural response to sexual and novel stimuli, humans and environmental conditions. Therefore "natural" behaviours that are essential or non-essential for good animal welfare require definition together with rationale for their inclusion or exclusion (Fraser and Broom, 1998).
Animal-choices approach

Animals have functional systems for controlling, for example, body temperature, nutritional state and social interactions. These functional systems (and the associated motivational systems) can be investigated and the resources required by, or important to, the animals can be identified (Broom and Johnson, 2000). This approach tells us about the animal’s needs. This approach has led to preference testing studies in animals where the preferences of animals for resources can be studied by allowing the animals to choose between resources. Preference in these studies is measured in either the time the animal spends with the resource or resources that are selected.

However, preference or choice testing has been criticized in two ways. Firstly Duncan (1978) suggested that the animal may not choose what is best for its welfare and secondly the action required in order to make the choice in an experiment is often very easy, and as a result there is little indication of the importance of the choice to the animal. Further research on the animal-choices approach is required. For example preferences may vary with age, response measured and time of day. In addition, experimental design may be confounded by the subjects’ familiarity with the resources or situation being compared and it is difficult to measure strength of preference (Duncan and Fraser, 1998).

3.5. The welfare of pigs in deep-litter, group housing systems

Deep-litter housing systems are perceived as being “welfare friendly” for pigs because they offer more pen space per pig, an enriched environment of deep-litter, together with the opportunity for increased social interaction between pigs. However, there is limited scientific literature on the welfare of growing pigs in deep-litter housing systems. Lay et al. (2000) found that pigs raised in deep-litter, group housing systems had fewer abnormal behaviours, performed more play behaviours, had lower plasma cortisol concentrations in response to the stressor of handling and lower leg injuries compared to pigs in a conventional housing system. Little is known of the social behaviours of pigs in deep-litter systems. Aggression, due to poor individual animal recognition may occur in large groups of pigs without stable social hierarchies. On the other hand, the enriched environment may reduce aggressive behaviours in large groups of pigs.
4. CONCLUSION

This review has shown that current knowledge of the social and feeding behaviour of pigs housed in large groups of 200 to 2000 pigs on deep-litter is poor. Social factors such as dominance hierarchy, group size, space allowance and physical factors such as feeding system, bedding and the thermal environment all have the potential to affect the social and feeding behaviour and stress physiology of growing pigs in deep-litter systems. Growing pigs in deep-litter systems have poor growth performance. In addition to possible animal welfare implications, these growth performance problems are limiting the adoption of this alternative housing system in the industry. The influence of social and feeding behaviour and stress physiology on growth performance of pigs in deep-litter group housing systems, are clearly aspects that require further investigation.
EXPERIMENT 1. AN ETHOGRAM OF BEHAVIOUR OF ENTIRE MALE GROWING PIGS IN A DEEP-LITTER, GROUP HOUSING SYSTEM AND A CONVENTIONAL HOUSING SYSTEM.

INTRODUCTION

Behaviour can be defined as the processes by which an animal senses both the internal state of its body and the external world and responds, i.e. behaviour is the perceivable part of any animal's reactions to its surroundings (Jensen et al., 1986). Behaviour can take place at many different levels of organization: from a small muscle contraction up to migration movements of complete herds of animals (Marler and Hamilton, 1966). An ethogram, or a behavioural catalogue, is a set of comprehensive descriptions of the characteristic behaviour patterns of a species. It is the result of many hours of behavioural observations and descriptions and should be the starting point of any ethological research (Lehner, 1996). The construction of an ethogram enables measurements of an animal's behaviour to be accurate and reliable (Jensen et al., 1986).

An ethogram of the behavioural repertoire of domestic free-ranging pigs has been defined by Stolba and Wood-Gush (1989) and in sows by Jensen (1980, 1982), however, an ethogram has not been defined for growing pigs housed in large groups on deep-litter. In order to define and study social and feeding behaviour of entire male growing pigs in deep-litter, group housing systems it was essential to define an ethogram of behaviours of growing pigs in a deep-litter system and a conventional group housing system in Experiment 1. The ethogram was used to identify the relevant social and feeding behaviours to measure in subsequent experiments.
MATERIALS AND METHODS

*Animals and housing treatment*

This experiment was conducted in a deep-litter, group housing system and a conventional housing system at a large commercial piggery in Corowa, New South Wales, Australia (36° latitude, 146.5° longitude). The two housing treatments were located approximately 3km apart. Nine hundred and eighty crossbred (Large White x Landrace) entire male growing pigs were used in this experiment. The pigs were 21 weeks old at the start of the experiment. Commercial male finisher diet (13.7 MJ/DE, 14.7% crude protein and 0.5g/MJDE available lysine) in a pelleted form was fed *ad libitum* in double spaced wet/dry feeders in both housing treatments. The experiment was conducted during autumn when the average daily temperatures ranged from a minimum of 10°C to a maximum of 21°C, with an average monthly rainfall of 53mm.

The two housing treatments studied were:

**Deep-litter system** – Four pens measuring 20 x 10m and housing 200 pigs per pen with 1 m² floor space per pig were used in this experiment. There were 8 pigs per feeding space. Rice hulls were provided for bedding at a rate of 0.7 kg/pig/day and were added only at the start of the experiment. The floor base under the rice hulls was graded earth with a cement render. The building was open-sided with natural ventilation. Blinds were positioned on the four sides of the building and were automatically controlled with the use of a thermostat.

**Conventional housing system** - Four pens measuring 4.5 x 7m and housing 45 pigs per pen with 0.7m² floor space per pig were used in this experiment. There were 8 pigs per feeding space. The pen flooring was 2/3 solid and 1/3 slatted. The building was open-sided with natural ventilation. Blinds were positioned on the four sides of the building and were automatically controlled with the use of a thermostat.
Behavioural observations

Focal-animal sampling, as described by (Jensen et al., 1986), was used to observe behaviour. Ten pigs per pen were randomly selected as focal-animals at the start of the experiment. Focal-pigs were identified by a large coloured ear tag in each ear and coloured spray marking (Dulux®Quick dry Spraypak™ paint) which was applied the day before observations. Each pen was observed four times over a two-week period. The sequence in which pens were observed was randomised, with 1 deep-litter pen and 1 conventional pen observed each day. Every observation day was divided into two sessions; 2h in the morning (0730 h to 0930 h) and 2h in the afternoon (1500 h to 1700 h). During each observation session each focal-pig was randomly selected and continuously observed for 6 min using a portable video camera.

The care and experimental use of pigs in this experiment conformed with the requirements of the Australian Prevention of Cruelty to Animals Act 1986 and the NHMRC “Australian code of practice for the care and use of animals for scientific purposes”.

Video data analysis

Descriptive terms were chosen to describe the behaviours observed. Ethograms of growing pigs by McGlone (1984, 1985), Stolba and Wood-Gush (1989) and Andresen and Redbo (1999) and group-housed dry sows by Jensen (1980, 1982) were used to assist in analysis and descriptions of the behaviour.

RESULTS

The following ethogram was defined for entire male growing pigs in the deep-litter system and the conventional system.

Postures

Standing: The pig is standing on all four legs. The pig can be still or moving about.
Sitting: The pig is sitting up with its front legs straight.
Lying: The pig is recumbent on its belly (sternal recumbency) or side (lateral recumbency). The pig is usually asleep.
Behavioural states/events

Locomotory

Walking: A slow regular symmetrical gait where the left legs perform the same movement as the right, but half a stride later, in which two of the four legs support the pig at any one time. The sequence of leg movements is left front, right hind, right front and left hind as described by (Fraser and Broom, 1998).

Trotting: A symmetrical gait of medium speed in which the pig is supported by alternating diagonal pairs of legs. The sequence of leg movements is left front and right hind, then right front and left hind as described by (Fraser and Broom, 1998).

Frolicking: The pig gallops along, sometimes travelling in a circular motion, moving around the body axis. This behaviour only occurs for a short period of time (deep-litter system only).

Maintenance

Drinking: The pig is standing at the drinker nozzle, assumed to be drinking.

Feeding: The pig is standing with its head in the feeder, assumed to be feeding.

Urination: The pig is standing still urinating. The front legs are slightly advanced which causes the back to depress and the pig urinates in squirts (Fraser and Broom, 1998).

Defecation: The pig is standing still defecating. The animal squats, curls its tail over its back, flattens its ears and half or fully closes its eyes (Fraser and Broom, 1998).

Tactile interactions

Social tactile interactions: These interactions can either have performer or receiver of the behaviour.

Anal nosing: The nose of a pig approaches within 5cm of the anus of another pig and makes physical contact.

Head-to-head knock: A rapid thrust upward or sideways with the head or snout against the neck, head or ears of another pig.

Levering: The pig puts its snout under the body of another pig (from behind or the side) and lifts the pig into the air.
**Mounting:** The pig places both front legs over the front or back of a pig. While mounted on the other pig it may thrust its hips, sometimes achieving an anal intromission with its penis and ejaculating either in the pig’s rectum or on the pig’s back.

**Nose-to-body:** The nose of a pig approaches within 5cm of any part of the body behind the ears, apart from the anal region and makes physical contact.

**Nose-to-nose:** The nose of a pig approaches and has physical contact with the nose, head or ears of another pig.

**Parallel pressing:** Two pigs stand side-by-side, pressing against each other’s shoulder, with one throwing its head against the head or the neck of the other pig. Pigs tend to champ their jaws causing saliva to froth.

**Pushing:** Pushing through a group of other pigs, without apparent interest in making social contact, often to get to the feeder.

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**Physical pen interactions**

**Jump:** The pig jumps down from the concrete ledge onto the bedding substrate (deep-litter system only).

**Nose pen fixtures:** The pig’s nose approaches within 5cm and touches a part of the pen other than the floor.

**Nosing concrete:** The nose of a pig approaches within 5cm of the concrete in the pen, and has physical contact with the concrete.

**Rooting:** The pig uses its nose to burrow into the deep litter bedding (deep-litter system only).

**Rooting/laying:** The pig uses its snout to burrow a small trench, then the pig lies down in the trench in the deep litter only.

**Rubbing:** The pig rubs the side of its body along a pen fixture.

**Rolling:** The pig lies down and moves sideways (deep-litter system only).

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**Other**

**Idle:** The pig is not performing the behavioural repertoire mentioned previously, or is asleep. The pig may be standing whilst idle.
DISCUSSION

The behaviours described in the results were identified as relevant behaviours to study the social and feeding behaviour of entire male growing pigs in deep-litter systems and conventional systems in subsequent experiments. The behaviours defined in the ethogram are similar to behaviours observed by Kelley et al. (1980), McGlone (1984, 1985) and Stolba and Wood-Gush (1989) in growing pigs and by Jensen (1980, 1982) in group-housed dry sows.

Locomotory behaviours are rather limited in pigs. While pigs are not well adapted for running per se, walking or trotting gaits are used for traversing large distances and galloping is used for flight (Signoret et al., 1975; Fraser and Broom, 1998). Frolicking, which was observed in the deep-litter treatment in the present experiment, has not been described by other authors, although ‘running and scampering’ which were described by Fagen (1981) as ‘play behaviours’, may be similar to frolicking.

Maintenance behaviours observed in the present experiment include feeding, drinking, defecating and urination. Pigs are omnivorous, and domesticated pigs on pasture will spend 6 to 7 h per day foraging. However, pigs in conventional housing systems on concentrated diets may only spend 15 min feeding (Signoret et al., 1975). Pigs usually drink 2 to 3 times as much water as the dry feed they are eating per day. However, feed restriction (Yang et al., 1981), high ambient temperatures and poor water quality may increase this ratio of up to 6 times (Gardner et al., 1990). Pigs will avoid defecating and urinating near their feeding area and thus when given the opportunity, specific sites within the pen are chosen for urination and defecation by a group of pigs (Whatson, 1978). This organised group eliminative behaviour is learnt throughout infancy (Fraser and Broom, 1998).

Social tactile interactions are important in maintaining the social organisation in pigs. Pigs are often described as ‘contact’ animals in which the animals rest in contact with each other (Hafez, 1975). Social tactile interactions such as nose-to-body, nose-to-nose and anal nosing have been described in growing pigs by Signoret et al. (1975) and in group-housed dry-sows by Jensen (1980,1982) and
were observed in the present experiment. Jensen (1980) concluded that these behaviours are involved in individual animal recognition, which is important when groups of animals need to establish effective competitive and cooperative social relationships (Stricklin and Mench, 1987). A common estimate of the total number of group members that can be recognised by an individual are 20 to 30 in pigs (Fraser and Broom, 1998). It is still uncertain how the mechanism of individual animal recognition operates in pigs, although it is evident that different types of recognition exist (Fraser and Broom, 1998). It appears that when pigs identify individuals within a group, auditory, olfactory, tactile and visual cues are important (Hart, 1985).

Agonistic behaviour was observed in both treatments in the present experiment. Agonistic behaviour refers to the species-typical threats and submissive behaviours, as well as conflict resolution through fighting. Aggressive behaviour is often used interchangeably with agonistic behaviour and in the strict definition refers to the attack and actual fighting (Hart 1985; Fraser and Broom, 1998). Parallel pressing, head-to-head knock and levering are defined as aggressive behaviours and have been reported by McBride et al. (1964), Beilharz and Cox (1967), Hafez and Signoret (1969), Signoret et al. (1975), Jensen (1980) and Fraser and Broom (1998). Agonistic behaviour in entire males has been described by Hafez and Signoret (1969) and the authors considered agonistic behaviours to be part of the establishment of the social hierarchy.

Mounting is described as a sexual behaviour and visual cues initiate this behaviour. It is not unusual for entire males reared in groups to form stable homosexual relationships (Signoret et al., 1975; Fraser and Broom, 1998). Mounting was observed in both treatments in the present experiment.
Social grooming rarely occurs among pigs and was not observed in this experiment, however social grooming was observed by Krosniunas (1979) and Stolba and Wood-Gush (1989). Pigs in a semi-natural environment formed small subgroups of the female with her offspring or other females and performed social grooming. It was concluded that this behaviour may be involved in maintaining social bonds within the social organisation. Pigs will rub (rubbing and rolling) against pen fixtures or upright objects and this may be considered part of their grooming behaviour (Signoret et al., 1975).

Frequent interactions with the physical pen such as rooting, jumping, nosing pen fixtures and nosing concrete were observed in the present experiment. These physical pen interactions indicate that pigs are exploratory animals with an appreciable proportion of their time spent manipulating and examining their environment (Wood-Gush and Vestergaard, 1989; Stolba and Wood-Gush, 1989). Pigs are highly motivated to perform rooting behaviour and it is an obvious feature of ingestive behaviour. The pig's snout is a highly developed sensory organ and olfactory cues play an important role in behaviour (Fraser and Broom, 1998). In unenriched environments with little complexity, pigs will tend to redirect this exploratory behaviour towards pen mates (Peterson et al., 1995), which may lead to tailbiting and cannibalism (Ewbank, 1973; Beattie et al., 1995; Fraser and Broom 1998).

In conclusion, Experiment 1 defined the behavioural repertoire of entire male growing pigs in deep-litter group housing and conventional group housing systems. It is these behaviours that need to be observed in order to quantify the effects of social and feeding behaviour on the growth performance and stress physiology of entire male growing pigs in deep-litter, group housing systems.
EXPERIMENT 2. THE SPATIAL LOCATION AND DISTANCE TRAVELLED BY ENTIRE MALE GROWING PIGS HOUSED IN A DEEP-LITTER, GROUP HOUSING SYSTEM.

INTRODUCTION
When pigs are housed either in deep-litter, group housing systems or conventional group housing systems they must maintain, use and negotiate the space around them in order to fulfil their basic physical and social requirements (Fraser and Broom, 1998). There are three types of space that an animal recognizes; the home range, territory and individual space. The home range is the area the animal habitually uses and usually contains a core area where the animal may rest. A territory is an area that is defended by fighting, or by demarcation which other individuals detect, thereby deterring entry. Individual space is the space used by animals, in which animals will usually have a minimum distance to others, and will prevent others from entering this space. Individual space also includes physical space that the animal requires to stand, lie down, feed etc. Animals maintain individual space to minimise damage to their body due to contact, to reduce interference during feeding, to reduce impedance when fleeing, for minimal disease transmission and to reduce the chance of rape (Broom, 1981; Fraser and Broom, 1998). Most members of a group of pigs will observe a social limit, which is the maximum distance any animal will move away from the group (Fraser and Broom, 1998).

The spacing behaviour of growing pigs housed in deep-litter systems is unknown. Furthermore, it is also unknown in the current scientific literature whether pigs housed in large groups in deep-litter systems return to a preferred lying area in the pen. Craig and Guhl (1969) studied flocks of 100 to 400 hens and found that hens in larger groups of 200 and above remained in particular areas of the pen and appeared to be "territorial" in the areas where they spent most of their time. The authors suggested that individual social recognition would be easier for the hens if they remained in a particular area of the shed, and associated with the same individuals daily. Intuitively it would appear beneficial for the animals to remain in smaller groups within a larger group, as excessive aggressive behaviour would be prevented.
Therefore the aim of the current experiment was to study whether growing pigs in deep-litter systems had preferred lying areas in the pen.

Furthermore, industry records show that pigs in deep-litter systems exhibit more non-infectious arthritis, stifle joint damage compared to pigs housed in conventional housing systems. This carcass damage results in the carcass being down graded. The cause of stifle joint damage of pigs in deep-litter systems may be related to a number of factors such as the distance travelled in the pens and an increase in social activity. Pigs in deep-litter systems are kept in much larger groups, and have substantially more pen space to move compared to conventionally housed pigs. Therefore, the current experiment also studied the relationship between behavioural variables such as the distance travelled in the pen and social tactile interactions and growth performance variables such as stifle-joint damage, carcass weight and carcass backfat.

MATERIALS AND METHODS

*Animals and housing*

This study was conducted in a deep-litter housing system at a large commercial piggery near Moulamein, New South Wales, Australia (35.5° latitude, 144.5° longitude). Two thousand four hundred crossbred (Large White x Landrace), 15 week old, entire male pigs were used. Two deep-litter buildings were used in the experiment. The buildings were 80 x 15m each holding 1200 pigs (i.e. 1200 pigs per pen). The pen space allowance was 1m² per pig. Commercial male finisher diet (13.7 MJDE, 14.7% crude protein and 0.5g/MJDE available lysine) was fed to the pigs in an *ad libitum* liquid feeding system. There were 8 pigs per feeding space. Rice hulls were provided for bedding at a rate of 0.7 kg/pig/day and were added only at the start of the experiment. The floor base under the rice hulls was graded earth with a cement render. The buildings were open-sided with natural ventilation. Blinds were positioned on 2 sides of the buildings and were automatically controlled with the use of a thermostat. The experiment was conducted during autumn when the average daily temperatures ranged from a minimum of 15°C to a maximum of 32°C with an average monthly rainfall of 33mm.
Behavioural observations

Focal-animal sampling, as described by (Jensen et al., 1986), was used to observe behaviour. Twenty pigs per pen were randomly selected as focal-animals at the start of the experiment. Focal-pigs were identified by a large coloured ear tag in each ear and coloured spray marking (Dulux® Quick dry Spraypak™ paint) which was applied 30 minutes prior to observation sessions. Spray marking the pigs 30 minutes prior to the behavioural observations was not thought to cause significant disruption to the behavior of the pigs beyond a few minutes. The pigs were familiar with stockpeople walking through the group pens on a regular basis, arousing them to stand to check for sick and injured pigs.

Each building was divided into 48 square grids with each grid consisting of 25m² of floor space. Each grid was allocated an x and y coordinate (x-1 to 3; y-1 to 16). Each observation day was divided into two sessions; 3 h in the morning (0800 h to 1100 h) and 3 h in the evening (1600 h to 1900 h). These observation times were chosen as they included both high and low periods of pig activity. The author and a trained technician conducted the behavioural observations. The grid location of each focal pig was observed and recorded at 10-min intervals during the observation sessions. Each building was observed for 4 consecutive days.

The distance travelled by pigs was determined by calculating the number of grids the focal-pig moved through during the total eight observation sessions. The ethogram from Experiment 1 was used to describe behaviours. Postures (standing, sitting, lying), locomotory behaviours (trotting, walking and frolicking), feeding, and agonistic and non-agonistic social tactile interactions (anal nosing, head-to-head knock, levering, mounting, nose-to-body, nose-to-nose, parallel pressing and pushing) were also observed and recorded at the same time the location data were recorded.
Carcass performance data

Carcass performance data were collected for each focal-pig. Data were collected approximately 20 minutes after evisceration, once the carcass had been de-haired and the viscera and testicles removed. Carcass weight was measured using a scale and was measured as head on and prior to the removal of flare fat. The carcass P2 back fat was measured using a Hennessey-Chong probe (P2) at the P2 site, 60mm from the pig’s midline immediately posterior to the last rib.

A stifle joint damage score was determined for each focal-pig as follows:
1 - no swelling, clear straw-coloured synovial fluid from all stifle joints when pricked.
2 - some swelling in 1 to 2 stifle joints; clear straw-coloured synovial fluid from joint when pricked.
3 - some swelling in 3 to 4 stifle joints; clear straw-coloured synovial fluid from joint when pricked.
4 - swelling in 1 to 2 stifle joints; thick bloody synovial fluid (non-infectious) emitted from joint when pricked.
5 - swelling in 3 to 4 stifle joints; thick bloody synovial fluid emitted (non-infectious) from joint when pricked.

The care and experimental use of pigs in this study conformed with the requirements of the Australian Prevention of Cruelty to Animals Act 1986 and the NHMRC “Australian code of practice for the care and use of animals for scientific purposes”.

Statistical analysis

A preferred lying area per observation session was defined per focal-pig. A preferred lying area for each session was defined as a pair of adjacent grids where the majority of lying bouts were observed in the observation session. A pair of adjacent grids rather than one grid was used since there was a number of examples where pigs were observed lying on or near the boundaries of grids. The number of different preferred lying areas over the 8 observation sessions was calculated. The most preferred pair of adjacent grids over the study period was defined as the pair with the highest frequency of lying bouts over the eight observation sessions.
The percentage of time spent lying in a preferred pair of grids was calculated by dividing the total number of lying bouts in the preferred pair of grids over the eight observation sessions. The distance travelled by pigs was determined by calculating the number of grids the focal-pig moved through during the total eight observation sessions.

A correlation analysis was conducted using Minitab (Release 11 for Windows™, 1996) statistical software. Data on individual focal-pigs (n=40) were used to examine the correlations between pig behaviour and productivity variables.

RESULTS
There was a significant (P<0.05) positive correlation between carcass weight and the number of social tactile interactions (Table 2.1). There were no significant (P>0.05) correlations between other behavioural variables and the productivity variables. However, there was a tendency (P<0.10) for pigs that had less social tactile interactions to have more stifle joint damage and to spend more time idle. Pigs that stood more often tended (P<0.10) to have higher carcass weights.

Table 2.1. Correlation coefficients between pig behaviour and productivity variables.

<table>
<thead>
<tr>
<th>Behavioural variables</th>
<th>Productivity variables</th>
<th>Carcass weight</th>
<th>Carcass P2 backfat</th>
<th>Stifle joint score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stand</td>
<td></td>
<td>0.262</td>
<td>0.035</td>
<td>-0.218</td>
</tr>
<tr>
<td>Sit</td>
<td></td>
<td>-0.045</td>
<td>-0.168</td>
<td>-0.042</td>
</tr>
<tr>
<td>Lie</td>
<td></td>
<td>0.101</td>
<td>0.128</td>
<td>0.113</td>
</tr>
<tr>
<td>Idle</td>
<td></td>
<td>-0.235</td>
<td>-0.078</td>
<td>0.261</td>
</tr>
<tr>
<td>Locomotion</td>
<td></td>
<td>0.110</td>
<td>0.021</td>
<td>-0.143</td>
</tr>
<tr>
<td>Feed</td>
<td></td>
<td>-0.124</td>
<td>-0.182</td>
<td>0.114</td>
</tr>
<tr>
<td>Agonistic and non-agonistic social tactile interactions</td>
<td>0.395*</td>
<td>0.142</td>
<td>-0.270</td>
<td></td>
</tr>
<tr>
<td>Distance travelled</td>
<td></td>
<td>0.247</td>
<td>0.092</td>
<td>-0.197</td>
</tr>
</tbody>
</table>

*P<0.05, r=0.31 (n=40)
As shown in Figure 2.1, the majority of pigs had 4 or more preferred lying areas over the 8 sessions. Similarly, most pigs spent less than 30% of their lying bouts in the most preferred area over the 8 sessions (Figure 2.2).

Figure 2.1. The number of preferred pairs of lying grids (lying areas) recorded for each of the 40 pigs.

Figure 2.2. Percent of time pigs spent in the preferred pair of grids (lying area) over the 8 sessions.
DISCUSSION

The results from this study show that the majority of entire male growing pigs in the deep-litter, group housing systems did not show a clear preference for a specific lying area over the observation period. Pigs maintain intense social contact behaviour and show comparatively little territorialism compared to other domesticated farm animals, except when they are raised under semi-natural or feral conditions (Fraser and Broom, 1998). The results from the current study suggest that the pigs are not territorial as the majority of pigs did not spend significant amounts of time in a preferred lying area. The current results differ from those found by Craig and Guhl (1969) in flocks of 100 to 400 hens. Hens in the larger groups of 200 and above tended to remain in particular areas of the pen and appeared to be “territorial” (defended their area) in those areas where they spent most of their time. The authors suggested that individual social recognition would be easier for the hens if they remained in particular area of the shed and associated with the same individuals daily. Intuitively it would appear beneficial for the animals to remain in smaller groups within a larger group, as excessive aggressive behaviour would be prevented.

Penny et al. (1997) investigated pig location preferences in small and large groups of growing pigs in deep-litter systems. The group sizes studied were 66 to 208 pigs. As group size decreased, pigs often lay in association with identified pen mates, and as group size increased, pigs returned to the same area of the pen more often. The authors concluded that pigs in large groups may return to a preferred location in the pen. One explanation for the differences observed between the current study and Penny et al. (1997) is that the group size was much larger (1200 pigs per pen) in the current study. Individual animal recognition may break down in such large groups of pigs, as pigs simply do not have the cues of social recognition. There is limited scientific literature on whether cues of social recognition are still functional and successful in maintaining stable social hierarchies in large groups.
Domestic pigs organise and maintain a dominance hierarchy throughout their life. The function of the dominance hierarchy is to reduce aggression within the group when resources are limited. A frequently used definition is “priority of access to an approach (to resources) or away from an avoidance situation” (Stricklin and Mench, 1987). The social organisation in pigs usually reflects a dominant and subordinate relationship (Hart, 1985) and dominance-submission relationships occur when there is a consistent relationship as the result of agonistic reactions between two pigs (Puppe, 1996). In large groups of animals, such as in the present study, resources such as floor space and feeder space may be readily available to all pigs and consequently the maintenance of a “territory” is unnecessary. This area of research obviously requires further investigation.

There was a significant positive correlation between carcass weight and social tactile interactions in the current study. It is generally accepted in the scientific literature that body weight is positively associated with dominance. Thus, larger pigs may be bolder in their interactions with other pigs (Ewbank, 1969).

Industry records show that pigs raised in deep-litter systems have a higher incidence of stifle joint damage compared to pigs in conventional housing systems. In the current study, stifle joint damage was not significantly associated with the distance travelled in the pen during observation periods. Perhaps stifle joint damage is related to physical factors such as condition of the deep-litter bedding. The risk of damage may increase if the litter becomes boggy and the pigs have difficulty moving through the litter. This situation would increase pressure on the stifle joints. Obviously research needs to be conducted on the effects of poor litter management on stifle joint damage in pigs.

The tendency for a negative association between stifle joint damage and number of social interactions is interesting. Stifle joint damage, by causing pain and lameness, may reduce activity and in turn social interactions. While the magnitude of the correlation was small, stifle joint damage and distance travelled was also negative.
Thus if the former association is real, and this requires further investigation, it is likely that stifle joint damage may reduce social interactions, rather than the reverse.

In conclusion, the results from Experiment 2 indicate that pigs housed in groups of 1200 pigs in deep-litter, group housing systems show no clear preference for a specific lying area in the pen. Furthermore there was no evidence that distance travelled in the pen was associated with stifle joint damage.
EXPERIMENT 3. THE SOCIAL AND FEEDING BEHAVIOUR OF ENTIRE MALE GROWING PIGS HOUSED IN A DEEP-LITTER, GROUP HOUSING SYSTEM AND A CONVENTIONAL HOUSING SYSTEM.

INTRODUCTION

Research has studied the social and feeding behaviour of individually and group housed pigs (Gonyou et al., 1992; de Haer and Merks, 1992; de Haer, 1992; de Haer and Merks, 1992; de Haer and de Vries, 1993a; Labroue et al., 1994; Nielsen et al., 1996 a,b; Spoolder et al., 1999). The social structure of wild swine, Sus scrofa, is the matriarchal herd, which consists of up to four females with their offspring. Mature boars are not permanently associated with the herd and may form ‘bachelor’ groups or remain solitary (Signoret et al., 1975). Stolba and Wood-Gush (1989) also observed this social structure in intensively reared domestic pigs living under natural conditions in the Edinburgh Pig Park. Domestication, genetic selection and intensive housing have modified this free-ranging foraging pig to a more docile animal (Sus scrofa domesticus) (Signoret et al., 1975). Group-housed, domestic pigs organise and maintain a dominance hierarchy throughout their life. Dominance hierarchies are developed to reduce aggression in groups of animals when resources are limited (Signoret et al., 1975).

In order for a group of animals to establish dominance hierarchies, it is necessary for the animals within the group to promptly identify and communicate with each other (Stricklin and Mench, 1987). It is still uncertain how the mechanism of individual animal recognition operates in pigs, although it is evident that different cues of social recognition exist (Fraser and Broom, 1998). It is possible that the number of pigs that can be individually recognized by a pig is less than the size of the group. Consequently, high levels of aggression may persist. It appears that when pigs identify individuals within a group, auditory, olfactory, tactile and visual cues are important (Hart, 1985; Stricklin and Mench, 1987). However, there is no scientific literature on the effects of large group sizes on the establishment of stable social hierarchies, or whether pigs have the ability to recognise each other in large groups.
There are significant differences in the feeding behaviour of growing pigs housed individually or in groups (de Haer and Merks, 1992). Individually housed pigs have more frequent, but shorter visits to the feeder, and eat less per visit compared to group housed pigs (de Haer and Merks 1992a; de Vries, 1993). Social effects in groups may be responsible for these differences in feeding pattern and the additional effects that large groups may have on feeding patterns is unknown. Social effects in groups may also prohibit some pigs feeding at preferred times. De Haer and Merks (1992) suggested that an increased level of social interaction in groups of pigs was responsible for longer but less frequent feeding bouts. Social facilitation may also stimulate groups of pigs to feed at similar times (Hsia and Wood-Gush, 1983), but social facilitation in large groups may increase the effort required to access feed, causing less frequent but longer feeding bouts.

Industry records have shown that pigs in deep-litter, group housing systems are 10 percent less efficient in converting feed to live weight gain and are 1 to 2 mm fatter compared to conventionally housed pigs (Connor, 1995; Brumm 1999; Honeyman et al., 1999; Payne, 1997; Payne et al., 2000). Our knowledge of both the social and feeding behaviour of pigs housed in deep-litter systems in groups of 200 or more pigs is very limited. It is essential to study the social and feeding behaviour of pigs in deep-litter systems to understand the effects of this housing system on pig growth performance and stress physiology.

Experiment 1 defined an ethogram of behaviours of entire male pigs in a deep-litter, group housing system and conventional group housing system. This ethogram was utilised in the present experiment in which the social and feeding behaviour of entire male growing pigs in a deep-litter and a conventional system were studied. A brief examination of stress physiology of pigs in the two housing systems, using an ACTH challenge to measure the responsiveness of the adrenal cortex, was also conducted.
MATERIALS AND METHODS

Animals and housing treatment

This experiment was conducted in a deep-litter, group housing system and a conventional housing system at a large commercial piggery in Corowa, New South Wales, Australia (36°S latitude, 146.5° longitude). The two housing treatments were located approximately 3km apart. Eight hundred and eighty crossbred (Large White x Landrace) entire male pigs were used. The pigs were 18 weeks old at the start of the experiment. Commercial male finisher diet (13.7 MJDE, 14.7% crude protein and 0.5g/MJDE available lysine) in a pelleted form was fed ad libitum in double-spaced, wet/dry feeders in both housing treatments. The experiment was conducted during winter when the average daily temperatures ranged from a minimum of 5°C to a maximum of 12°C, and the average monthly rainfall was 62mm.

The two housing treatments were:

Deep-litter system - Four pens measuring 20 x 10m with 200 pigs per pen with 1 m² floor space per pig were used. There were 8 pigs per feeding space. Rice hulls were provided for bedding at a rate of 0.7 kg/pig/day and were added only at the start of the experiment. The floor base under the rice hulls was graded earth with a cement render. The building was open-sided with natural ventilation. Blinds were positioned on four sides of the building and were automatically controlled with the use of a thermostat.

Conventional housing system - Four pens measuring 2.7 x 3.6m were used in the experiment. Twenty pigs were housed in each of these pens at the start of the experiment, provided with a space allowance of 0.48²/pig. When the average pig live weight was 60 kg, five non-focal pigs were removed from each pen to provide a space allowance of 0.65m²/pig. At this stage there were 8 pigs per feeding space. The concrete pen floor was 2/3 solid and 1/3 slatted. The building was open-sided with natural ventilation. Blinds were positioned on two sides of the building and were automatically controlled with the use of a thermostat.
Behavioural observations

Activity and social behaviour observations - The social behaviour of the pigs was directly recorded by the author using "The Observer ©" (Noldus Information Technology, 1995) package on a portable computer. Observation platforms were erected 3m above the deep-litter and conventional pens to reduce distractions to the pigs. Focal-animal sampling, as described by (Jensen et al., 1986), was used to observe behaviour. Ten pigs per pen were randomly selected as focal-animals at the start of the experiment. Focal-pigs were identified by a large coloured ear tag in each ear and coloured spray marking (Dulux®Quick dry Spraypak™ paint) which was applied to the pigs' backs the day before observations. Each pen was observed eight times over a 4-week period. The sequence in which pens were observed was randomised. Every observation day was divided into two sessions: 2 h in the morning (0730 h to 0930 h) and 2 h in the afternoon (1500 h to 1700 h). During each observation session each focal-pig was randomly selected and continuously observed for 6 min using direct observation.

Social behaviour was measured using the ethogram defined in Experiment 1. Postures were recorded as the percentage of observation time spent standing, sitting or lying. The time spent by pigs in the standing posture was used as an estimate of total activity. The activity and social behaviours were pooled into the following categories: idle, locomotory (walking, frolicking and trotting), non-social, physical pen interactions (jump up on cement feeding pad, nose pen fixtures, nosing concrete, rooting, rubbing and rolling), agonistic behaviours (parallel pressing, head-to-head knocks and leveraging - performed and received), sexual behaviours (mounting - performed and received) and social tactile interactions (anal nosing, nose-to-body, nose-to-nose and pushing-performed and received).

Means (±SED) for the duration of the behaviour were expressed as percentage of observation time and the frequency of behaviour means were expressed as number of occurrences in 6 min using a bout criterion interval of 5s (Jensen et al., 1986).
Feeding behaviour observations - Feeding behaviour was recorded using time-lapse with video cameras positioned above the feeding areas in the deep-litter and conventional housing treatments. Each pen was video recorded once a week, for two weeks prior to slaughter at 23 weeks of age. Recordings were made during day-light hours from 0730 h to 01730 h.

The video-taped data were viewed and feeding behaviour was measured using the following parameters:

*Total time within 1 m of feeder* (s): the total time spent within 1 m of the feeder.
*Total time feeding* (s): the total time the pig's head was in the feeder (assumed to be feeding).
*Number of feeding bouts*: the number of times a pig put its head in the feeder (assumed to be feeding).
*Average duration of feeding bouts* (s): the average duration of feeding bouts.
*Number of social interactions within 1 m of the feeder*: number of social tactile interactions performed and received (i.e. pushing, head-to-head knocks, anal nosing, levering, mounting, nose-to-body, nose-to-nose, parallel pressing and pushing) within 1 m of the feeder.

Feeder occupancy during day-light hours was measured by counting the number of pigs with their head in the feeder at 10 min intervals during the feeding observation period.

Growth performance

The focal pigs in both housing treatments were individually weighed and P2 back fat was measured at 18 and 22 weeks of age. The P2 back fat was measured at the P2 site, 60 mm from the pig's midline immediately posterior to the last rib, using a Toshiba SAL-32B real-time ultrasound with a PLB-508M 5MHZ linear array probe.
Carcass performance data were collected for all focal pigs, approximately 20 min after slaughter, once the carcass had been de-haired and the viscera and testicles removed. Carcass weight was measured and the carcass back fat was measured using a Hennesey-Chong probe (P2) at the P2 site. Dressing percentage was measured, and refers to the carcass weight/live weight of the pig, expressed as a percentage.

*Stress Physiology - ACTH Challenge*

The rationale for an ACTH challenge as a measure of stress physiology is that long-term stimulation of the HPA axis results in increased sensitivity of the adrenal cortex to ACTH. Adrenal gland responsiveness (changes in the HPA axis) in pigs can be assessed on the basis of the cortisol response to an intramuscular injection of 50 IU ACTH (Broom and Johnson, 2000). The focal-pigs from the two treatments were drafted and trucked to another building and housed in a conventional pen for 2 days before the ACTH challenge was conducted. Pigs were housed in pens measuring 1.9 x 3.6 m with other focal-pigs from the same group. There were 10 pigs per pen with a floor space of 0.68 m² per pig. The pigs were fed in a double spaced wet/dry feeder.

Four out of the 10 focal-pigs in each pen were randomly selected for the ACTH challenge (i.e. 16 pigs per housing treatment). A snout-rope was placed around the pig's nose to limit movement of the pig and 8 ml blood was collected by jugular venipuncture, with all pigs in each group bled within 2 minutes.

Each pig was then given an intramuscular injection of 50 IU/2ml ACTH (Synacthen® CIBA-GEIGY Australia Ltd.) into the neck. One hour after the ACTH injection, a second 8 ml blood sample was collected from each pig using the same venipuncture technique. The blood samples were centrifuged at 2000 rpm for 10 min at 6°C. The plasma was harvested and stored at -20°C until analysis. The samples were analysed for porcine serum cortisol (total cortisol) by the Endocrinology RIA Service at the Victorian Institute of Animal Science, Attwood, Australia.
The care and experimental use of pigs in this experiment conformed with the requirements of the Australian Prevention of Cruelty to Animals Act 1986 and the NHMRC “Australian code of practice for the care and use of animals for scientific purposes”.

**Statistical analysis**

The experimental unit was the pen group and the data were analysed by analysis of variance using Minitab (Release 11 for Windows™, 1996) statistical software. The source of variation is presented in Table 3.1.

**Table 3.1 Source of variation for experimental design.**

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>Degrees of freedom</th>
</tr>
</thead>
<tbody>
<tr>
<td>Housing treatment</td>
<td>1</td>
</tr>
<tr>
<td>Error</td>
<td>6</td>
</tr>
<tr>
<td>Total</td>
<td>7</td>
</tr>
</tbody>
</table>

**RESULTS**

*Activity and social behaviour*

There was a significant difference between the activity levels, based on time spent standing, and the social behaviour of pigs in the two treatments (Table 3.2). Pigs housed in the deep-litter system spent more time (P<0.01) standing and less (P<0.05) time sitting and lying compared to conventionally housed pigs.

Pigs in the deep-litter treatment spent more (P<0.001) time in locomotion than pigs in the conventional treatment and there was a higher frequency of exploratory behaviours displayed by pigs in the deep-litter housing treatment, as shown by an increase (P<0.05) in physical pen interactions (Table 3.2).

Pigs housed in a deep-litter system had a higher (P<0.001) incidence of social tactile interactions away from the feeding area during the observation period (Table 3.2). Pigs in the deep-litter system also spent more time conducting agonistic (P<0.001) and sexual behaviours (P<0.01).
Table 3.2: Mean (±SED) time entire male growing pigs housed in deep-litter and conventional housing treatments spent in different postures and behaviours, away from the feeder.

<table>
<thead>
<tr>
<th>Postures (% observation time spent):</th>
<th>Deep-litter</th>
<th>Conventional</th>
<th>SED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standing</td>
<td>44.1&lt;sup&gt;c&lt;/sup&gt;</td>
<td>25.1&lt;sup&gt;d&lt;/sup&gt;</td>
<td>4.48</td>
</tr>
<tr>
<td>Sitting</td>
<td>1.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>6.5&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.81</td>
</tr>
<tr>
<td>Lying</td>
<td>54.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>68.4&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.05</td>
</tr>
</tbody>
</table>

Behaviours:

<table>
<thead>
<tr>
<th>Behaviours</th>
<th>Deep-litter</th>
<th>Conventional</th>
<th>SED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Idle</td>
<td>54.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>68.4&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.06</td>
</tr>
<tr>
<td>Locomotory (% observation time)</td>
<td>10.4&lt;sup&gt;e&lt;/sup&gt;</td>
<td>2.0&lt;sup&gt;f&lt;/sup&gt;</td>
<td>0.76</td>
</tr>
<tr>
<td>Physical pen interactions (frequency)</td>
<td>9.4&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.6&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.52</td>
</tr>
<tr>
<td>Social tactile interactions (frequency)</td>
<td>8.3&lt;sup&gt;e&lt;/sup&gt;</td>
<td>3.7&lt;sup&gt;f&lt;/sup&gt;</td>
<td>0.60</td>
</tr>
<tr>
<td>Agonistic (% observation time)</td>
<td>4.3&lt;sup&gt;e&lt;/sup&gt;</td>
<td>0.7&lt;sup&gt;f&lt;/sup&gt;</td>
<td>0.48</td>
</tr>
<tr>
<td>Sexual (% observation time)</td>
<td>1.8&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.6&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.30</td>
</tr>
</tbody>
</table>

<sup>a, b, c, d, e, f</sup> Within rows, means with different superscripts are significantly different at P<0.05, P<0.01 and P<0.001, respectively.

**Feeding Behaviour**

Pigs in the deep-litter treatment spent less time (P<0.05) within 1 metre of the feeder, had fewer (P<0.05) feeding bouts and a longer (P<0.05) duration of feeding compared to pigs in the conventional housing treatment (Table 3.3). Pigs in the deep-litter housing treatment also had a lower (P<0.05) frequency of social interactions around the feeder than those in the conventional housing treatment. There was a tendency (P=0.06) for the average percentage of feeders occupied during day light hours to be higher in the conventional housing treatment.
Table 3.3. Mean (±SED) feeding behaviour of entire male growing pigs housed in deep-litter and conventional housing treatments.

<table>
<thead>
<tr>
<th></th>
<th>Deep-litter</th>
<th>Conventional</th>
<th>SED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total time within 1 m of feeder (s)</td>
<td>3776&lt;sup&gt;a&lt;/sup&gt;</td>
<td>6483&lt;sup&gt;b&lt;/sup&gt;</td>
<td>759.9</td>
</tr>
<tr>
<td>Total time feeding (s)</td>
<td>1554</td>
<td>1724</td>
<td>198.5</td>
</tr>
<tr>
<td>Number of feeding bouts</td>
<td>30.5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>52.9&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4.32</td>
</tr>
<tr>
<td>Average duration of feeding bouts (s)</td>
<td>52.4&lt;sup&gt;a&lt;/sup&gt;</td>
<td>33.3&lt;sup&gt;b&lt;/sup&gt;</td>
<td>6.96</td>
</tr>
<tr>
<td>Number of social interactions within 1 m of the feeder</td>
<td>17.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>37.8&lt;sup&gt;b&lt;/sup&gt;</td>
<td>8.19</td>
</tr>
<tr>
<td>Average % of feeders occupied during day light hours (0730 h to 01730 h)</td>
<td>43.28</td>
<td>53.77</td>
<td>4.53</td>
</tr>
</tbody>
</table>

<sup>a, b</sup> Within rows, means with different superscripts are significantly different at P<0.05.

Figure 3.1 suggests also that there was greater use of the feeders (i.e. a higher proportion of feeder space occupied) by pigs throughout much of the day in the conventional housing system compared to the deep-litter system.

Figure 3.1. Daily feeding pattern. Percentage of feeders occupied throughout the day in the deep-litter (---) and conventional (-----) housing treatments.
Growth performance

There were no significant (P>0.05) differences between the two housing treatments in live weight and P2 back fat at 18 and 22 weeks, however the conventionally housed pigs had a higher (P<0.05) rate of gain and dressing % (Table 3.4).

Table 3.4. Mean (±SED) growth performance of entire male growing pigs housed in deep-litter and conventional housing treatments.

<table>
<thead>
<tr>
<th></th>
<th>Deep-litter</th>
<th>Conventional</th>
<th>SED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Live weight (kg) at 18 weeks of age</td>
<td>63.07</td>
<td>61.18</td>
<td>2.68</td>
</tr>
<tr>
<td>Live weight (kg) at 22 weeks of age</td>
<td>87.6</td>
<td>91.3</td>
<td>4.72</td>
</tr>
<tr>
<td>Rate of Gain (kg/day)</td>
<td>702.5\textsuperscript{a}</td>
<td>859.0\textsuperscript{b}</td>
<td>0.06</td>
</tr>
<tr>
<td>P2 back fat (mm) at 18 weeks of age</td>
<td>7.26</td>
<td>7.15</td>
<td>0.35</td>
</tr>
<tr>
<td>P2 back fat (mm) at 22 weeks of age</td>
<td>9.53</td>
<td>9.13</td>
<td>0.62</td>
</tr>
<tr>
<td>Carcass weight (kg)</td>
<td>69.82</td>
<td>74.16</td>
<td>3.27</td>
</tr>
<tr>
<td>Carcass P2 back fat (mm)</td>
<td>10.49</td>
<td>10.91</td>
<td>0.76</td>
</tr>
<tr>
<td>Dressing %</td>
<td>78.87\textsuperscript{a}</td>
<td>81.37\textsuperscript{b}</td>
<td>0.76</td>
</tr>
</tbody>
</table>

\textsuperscript{a, b} Within rows, means with different superscripts are significantly different at P<0.05.

Stress Physiology

There were no significant (P>0.05) differences between the two housing treatments in the increase in cortisol concentration following an ACTH injection (Table 3.5).

Table 3.5. Mean (±SED) plasma cortisol concentrations (nM) of pigs raised in deep-litter and conventional housing system at 1300h and 1400h (1 h after an ACTH challenge injection) and percent increase in cortisol following an ACTH challenge.

<table>
<thead>
<tr>
<th></th>
<th>Deep-litter</th>
<th>Conventional</th>
<th>SED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cortisol (nM) at 1300h</td>
<td>56.9</td>
<td>56.3</td>
<td>5.12</td>
</tr>
<tr>
<td>Cortisol (nM) at 1400h</td>
<td>263.8</td>
<td>234.6</td>
<td>27.76</td>
</tr>
<tr>
<td>Percent increase in cortisol following an ACTH challenge</td>
<td>436.5</td>
<td>345.4</td>
<td>97.79</td>
</tr>
</tbody>
</table>
DISCUSSION

The results of the present experiment indicate that there were significant differences in the social and feeding behaviour of entire male pigs housed in a deep-litter, group housing system and a conventional housing system. These behavioural differences may be responsible for the reported differences in growth performance between deep-litter and conventional housing systems (Connor, 1995; Brumm, 1999; Honeyman, et al., 1999; Payne et al., 2000). However, surprisingly, there was no significant difference in live weight and P2 backfat at 18 and 23 weeks. However, the pigs in the conventional housing treatment had a higher average daily gain and dressing %. Variations that may occur between production systems, such as in climate and disease may have confounded treatment effects on growth performance in the present experiment.

Pigs in the deep-litter treatment were spent more time standing and performing exploratory behaviours than pigs in the conventional housing treatment. The results are similar to previous observations. Dinussis (1965) showed that pigs kept in conventional housing systems and fed concentrated diets may rest (lying) for up to 80 % of the time.

Lyons et al. (1995) studied the behaviour of entire male pigs in groups of 15 in deep-straw and conventional slatted pens. Pigs housed on deep straw spent more time standing and straw directed behaviour occupied approximately 26% of their time during the day. Pigs in conventional pens have long periods of inactivity each day in which they are idle (Fraser and Broom, 1998). On the other hand, pigs in a semi-natural environment will spend up to half of the daylight hours foraging and rooting (Stolba and Wood-Gush, 1989). Pigs in the deep-litter treatment in the present experiment did not spend as much time performing locomotory behaviours and exploring the environment as that observed by Stolba and Wood-Gush (1989). Presumably, the semi-natural environment provided by Stolba and Wood-Gush (1989) which consisted of large paddocks and different habitat types, motivated the pigs to explore and to be more active.
Nutritional differences and the feeding system may also be responsible for differences in exploration. The effects of environmental enrichment on behaviour have been studied by Wood-Gush and Vestergaard (1989 a,b) and Beattie et al. (1995, 1996, 2000 a,b) and all have shown that environmental enrichment increases the incidence of pen tactile interactions as was observed in the present experiment.

The pigs in the deep-litter treatment had a higher frequency of social tactile interactions and spent significantly more time performing agonistic behaviours compared to their conventionally housed counterparts. These results are in agreement with Lay et al. (2000). Pigs in the deep-litter housing treatment in the current experiment also spent significantly more time in locomotory behaviours (trotting, walking and frolicking). This may have contributed to the increase in pig tactile interactions in the deep-litter system as being more active, pigs in the deep-litter system are more likely to frequently encounter and interact with other pigs. McKinnon et al. (1989) studied weaner pigs housed with or without straw, in groups of 13 pigs, and found that pigs were more active when provided with straw, however there were more social tactile interactions without straw, which is contrary to the observations in the present experiment.

Another explanation for the increase in tactile social interactions in the deep-litter treatment in the present experiment may be related to problems with the social structure of the group. The social stability of a group of pigs relies on the development of a stable dominance hierarchy, which is usually established after mixing and results in reduced aggression within a few hours (Spoolder et al., 1999). However group size may affect the establishment of a stable dominance hierarchy.

In order for a group of animals to establish a dominance hierarchy, it is necessary for the animals within the group to promptly identify each other (Stricklin and Mench, 1987). It appears that auditory, olfactory, tactile and visual cues are important in pigs recognizing other pigs (Hart, 1985). It has been hypothesised that group size is positively correlated with a failure to resolve rank disputes without aggression (Al-Rawi and Craig, 1975) because of recognition problems in large groups.
Spoolder et al. (1999) studied groups of 20, 40 and 80 pigs and the larger groups of pigs had significantly more skin lesions. Skin lesions were not measured in the present experiment, although industry evidence suggests that pigs housed in deep-litter systems have significantly more carcass damage compared to conventionally housed pigs (Connor 1995; Brumm, 1999; Honeyman et al., 1999).

In larger groups, individuals are more likely to encounter other pigs which they do not recognise or with which they have to reconfirm their relative rankings, resulting in aggression and more carcass bruising (Spoolder et al., 1999). Experiments conducted on laying hens (Bilecik and Keeling, 2000) have shown that the highest levels of feather pecking and aggressive attacks were in the largest group of hens. Fraser and Rushen (1987) reviewed the literature on aggression in pigs and stated that increases in group size and a reduction in floor space were associated with a higher incidence of aggression. However, the majority of experiments on pigs examined group sizes of 60 or less.

On the other hand, Pagel and Dawkins (1997), Hughes et al. (1997), Estevez (1998) and Nicol et al. (1999) showed that aggressive behaviour declines as group size increases. The authors suggested that the greater availability of resources such as total free space, availability of feeding places and preferred lying areas may eliminate the need for a dominance hierarchy, which functions to control aggression when resources are limited (Hemsworth and Barnett, 2001). Perhaps animals in large groups are more socially tolerant (Hughes et al., 1997) and abandon all attempts to establish social hierarchies (Pagel and Dawkins, 1997).

The experiments conducted by Spoolder et al. (1999) on the effects of group size used pens without deep-litter or straw. The authors suggested that perhaps social tactile interactions would be less if straw was present, as the provision of straw has been suggested to reduce social tactile interactions (Fraser et al., 1991). Both the role of large groups and deep-litter in large groups on aggression require further study.
Feeding behaviour was affected by the housing system in the present experiment. Pigs in the deep-litter treatment spent less time near the feeder, had less feeding bouts and had feeding bouts of longer duration than pigs in the conventional treatment. Pigs in the deep-litter treatment also had a lower frequency of social interactions around the feeder, which may have caused less interruption during feeding and led to the longer duration of the feeding bout.

De Haer and Merks (1992), Nielsen and Lawrence (1993) and Nielsen et al. (1995 a, b) have studied the feeding behaviour of individually and group housed pigs, and have all found significant differences in feeding behaviour between the two housing systems: group housed pigs ate less frequently and had larger meals compared to individually housed pigs. The authors suggested that the change in feeding behaviour between individually and group housed pigs was caused by an increased level of social interaction in the group of pigs. Pigs housed individually do not have these social influences disrupting their feeding pattern. In fact, Nielsen and Lawrence (1993) found that the number of visits to the feeder decreased and duration of feeding increased as group size increased, however the maximum group size was only 20 pigs.

There are large differences in the pen geometry between the deep-litter and conventional pens. Pigs have more pen space, and ultimately more total effective space in the deep-litter pens, which may result in them using pen space away from the feeder for non-feeding behaviours. On the other hand, pigs in the conventional pens have less pen space and may use the pen space within 1 m of the feeder for non-feeding behaviours such as lying down or social tactile interactions. It is these differences in pen geometry that may contribute to the changes in the pig’s feeding behaviour. Difficulties in gaining and maintaining feeder access in the conventional pens, due to limited pen space, may be responsible for the shorter but more frequent feeding bouts observed in these pigs. It is possible that the relatively unrestricted feeding that occurred in deep-litter systems, perhaps as a result of less tactile interactions, may result in the reported increased fat deposition and poorer feed conversion in these systems.
The scientific literature suggests that small, frequent feeding bouts throughout the day are more efficient than larger less frequent feeding bouts that occur less frequently. Quiniou et al. (1999) studied the effect of feeding behaviour on growth performance of Pietrain and Mieshan pigs and concluded that differences observed between these breeds in growth performance were related to differences in feed intake and feeding behaviour. The leaner Pietrain pigs had a higher frequency of small meals throughout the day while fatter Mieshan pigs had a smaller frequency of large meals. The authors concluded that a higher propensity for fat deposition was associated with a reduced number of meals, whereas a smaller number of meals taken more frequently may favour protein deposition. Full-spaced meals lead to an increased body fat, decreased body protein and water, increased urinary nitrogen excretion and higher food to gain ratio than more frequent small meals (Cohn et al., 1962). The results of these nutritional studies and the observation on feeding behaviour in the present experiment support the view that the feeding behaviour of pigs in deep-litter systems may contribute to their poorer growth performance.

The results from the ACTH challenge, which tested the responsiveness of the HPA axis, suggest that there was no substantial difference between housing treatments in basal plasma cortisol concentration. These results are in contrast to experiment conducted by Lay et al. (2000), in which deep-litter pigs were found to have a lower cortisol concentration following a handling procedure compared to conventionally housed pigs. The change in housing for the pigs in both housing treatments in the current experiment was essential to facilitate blood collection for the ACTH challenge. This environmental change may have masked treatment effects in response to ACTH in the deep-litter treatment. Even though pigs in the conventional and deep-litter treatment were moved to different pens, and had the stressor of transporting imposed, the pigs in the deep-litter treatment may have taken longer to settle into the conventional pens, compared to the pigs is the conventional treatment (i.e. the HPA axis was still “sensitive” due to changes in group size, environment, human contact etc.). Obviously further research on the stress physiology of pigs in deep-litter systems is required to examine the possibility that increased stress affects growth performance of pigs in deep-litter systems.
In conclusion, the results from Experiment 3 show that there are differences in the social and feeding behaviour of entire male pigs in deep-litter and the conventional housing system. These differences may influence the growth performance of pigs in deep-litter, group housing systems.
EXPERIMENT 4. THE EFFECT OF RESTRICTING PEN SPACE AND FEEDER AVAILABILITY ON THE BEHAVIOUR AND GROWTH PERFORMANCE OF ENTIRE MALE GROWING PIGS IN A DEEP-LITTER, GROUP HOUSING SYSTEM.

INTRODUCTION

Experiment 3 investigated the social and feeding behaviour of entire male growing pigs housed in deep-litter, group housing and conventional group housing systems. The feeding behaviour of deep-litter, group housed pigs was different to that of conventionally housed pigs. Pigs in the deep-litter housing treatment had longer feeding bouts, which occurred less frequently than pigs in the conventional housing treatment. One interpretation, based on differences in social tactile interactions around the feeder, is that the pigs in the deep-litter treatment may have had unrestricted access to the feeder perhaps due to less disruption by other pigs in the feeding area. It is possible that this change in feeding behaviour may result in increased fat deposition and poorer feed conversion efficiency because of changes in feeding patterns that may affect feed utilisation.

The scientific literature suggests that small, frequent feeding bouts throughout the day are more efficient in the utilisation of feed than longer but less frequent feeding bouts. Feed intake pattern and growth performance can be related through a number of metabolic pathways such as a relationship between digestibility and utilisation of energy and nutrients (de Haer, 1992). Pigs that have shorter, frequent feeding bouts have a more continuous flow of digesta through the intestine (Ruckebusch and Bueno, 1976), an increase in the production of amylase and a decrease in lipase to promote digestion (Hee et al., 1988). As meal size increases or the frequency of feeding bouts increase, gastric emptying increases, which reduces the efficiency of digestion as there is less fermentation occurring in the hindgut (Van Es, 1982).
Quiniou et al. (1999) studied the effect of individual housing on growth performance and feeding behaviour of growing pigs. The authors concluded that differences observed in growth performance were related to differences in feeding behaviour and that a higher propensity for fat deposition was associated with a reduced number of meals, whereas a smaller number of meals was favourable towards protein deposition. Cohn et al. (1962) also found that full-spaced meals resulted in increased body fat and higher food to gain ratio compared with frequent small meals. The availability of amino acids for growth and fat deposition may be influenced by the pattern of feed intake (Batterham and Bayley, 1989). The poor growth performance of pigs in deep-litter housing systems may be due to less frequent but longer feeding bouts that occur in these systems.

The aim of Experiment 4 was to test the hypothesis that longer but less frequent feeding bouts in deep-litter, group housing systems contribute to the poor growth performance in these systems. Changes in pen space and feeder availability in a deep-litter system were used in an attempt to change feeding patterns and in turn evaluate the effects on growth performance.

MATERIALS AND METHODS

Animals and housing

This experiment was conducted using deep-litter systems at a large commercial piggery near St Arnaud, Victoria, Australia (36.5°S latitude, 143.5° longitude). Two thousand, four hundred and sixty crossbred (Large White x Landrace) entire male growing pigs were housed in groups of 205 in a deep-litter, group housing system. Twelve pens in six, 2-pen sheds at one location were used in the experiment. The pens measured 20 x 9m with a floor space of 1m² per pig. Rice hulls were provided for bedding at a rate of 0.7 kg/pig/day and were added only at the start of the experiment. The floor base under the rice hulls was graded earth with a cement render. The building was open-sided with natural ventilation. Blinds were positioned on two sides of the buildings. Commercial male finisher diet (13.7 MJDE, 14.7% crude protein and 0.5g/MJDE available lysine) in a pelleted form was fed to the pigs ad libitum in double spaced wet/dry feeders.
The experiment was conducted during spring and summer. The average daily temperatures ranged from a minimum of 5°C to a maximum of 17°C with an average monthly rainfall of 42mm for the first half of the experiment. For the remainder of the experiment, the average minimum and maximum daily temperatures were 15°C and 30°C, respectively, with an average monthly rainfall of 26mm.

Experimental treatments

The experimental design was a 2 x 2 factorial, comparing pen space allowance and feeder availability in a deep-litter, group housing system. The two main factors studied were:

1. **Feeder availability** - groups of pigs were provided with feeders at a ratio of either (i) 9 or (ii) 15 pigs per feeder space at 10-23 weeks of age. Access to a bank of feeders was obstructed in the restricted feeder treatment (15 pigs per feeder space) to achieve the reduction (Figure 4.1).

2. **Pen space allowance** - groups of pigs were provided with a space allowance of either 0.45 m² per pig from 10 to 13 weeks of age, 0.55 m² per pig from 14 to 16 weeks of age, and subsequently 0.74 m² per pig from 17 to 23 weeks of age or 1 m² per pig from 10 to 23 weeks of age. A portable fence made from conveyor belt rubber was erected in the pens to restrict pen space (Figure 4.1).

![Figure 4.1 The location of the feeders on a concrete pad and portable fence.](image-url)
There were three replicates (pens) of each of the four treatments (Table 4.1). Within blocks of 2 adjacent sheds (4 pens), pens were randomly allocated to the 4 treatments.

### Table 4.1. Experimental design for the 2 x 2 factorial experiment. The two main factors studied were pen space and feeding spaces.

<table>
<thead>
<tr>
<th></th>
<th>Unrestricted space pen and unrestricted feeding space</th>
<th>Unrestricted space pen and restricted feeding space</th>
<th>Restricted space pen and unrestricted feeding space</th>
<th>Restricted space pen and restricted feeding space</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of pens</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Total pigs</td>
<td>3 x 205</td>
<td>3 x 205</td>
<td>3 x 205</td>
<td>3 x 205</td>
</tr>
</tbody>
</table>

*Behavioural observations*

Social and feeding behaviour observations were conducted when the pigs were 10, 17 and 23 weeks of age. The second two sets (at 17 and 23 weeks of age) of observations were conducted just prior to the portable fence being moved in the restricted pen space treatments. Ten animals per group were randomly selected as focal animals at the beginning of the experiment (Jensen et al., 1986). These pigs were identified by a coloured ear tag in each ear and coloured spray marking (Dulux®Quick dry Spraypak™) which was applied the day before observations.

*Social behaviour observations* - The author manually recorded the social behaviour by direct observation. Observation platforms were erected 2m above the pens to reduce distraction to the pigs. The sequence in which pens were observed was randomised. Every observation day was divided into two sessions: 2 h in the morning (0730 h to 0930 h) and 2 h in the afternoon (1500 h to 1700 h). During each observation session, each focal-pig was randomly selected and continuously observed for 5 minutes using direct observation. Each focal pig was observed twice a week at 10, 17 and 23 weeks of age. Each pen was observed six times during the experiment.
Social behaviour was measured using the ethogram defined in Experiment 1. Postures were recorded as the percentage of observation time spent standing, sitting or lying. The activity and social behaviours were pooled into the following categories; idle, locomotory (walking, frolicking and trotting), physical pen interactions (jump up on cement feeding pad, nose pen fixtures, nosing concrete, rooting, rubbing and rolling), agonistic behaviours (parallel pressing and head knocks - performed and received), sexual behaviours (mounting - performed and received) and social tactile interactions (anal nosing, nose-to-body, nose-to-nose and pushing - performed and received). Means (± SED) for social behaviour were expressed as number of occurrences in 5 min using a bout criterion interval of 5 seconds (Jensen et al., 1986).

Feeding behaviour observations - Feeding behaviour was recorded using video cameras positioned above the feeding platform and connected to time-lapse video recorders. Recordings were made during day light hours (0540h to 1830 h) for observation period 1 (10 weeks of age) and for a 23 hour period (17 and 23 weeks of age) for observation periods 2 and 3. Each pen was video recorded once during the three observation periods.

The video-taped data were viewed and feeding behaviour was measured by the author and one trained technical assistant using the following parameters:

Total time within 1 m of feeder (s): the total time the focal pig spent within 1 m of the feeder.

Total time feeding (s): the total time the focal pig’s head was in the feeder (assumed to be feeding).

Number of feeding bouts: the number of times the focal pig put its head in the feeder (assumed to be feeding).

Average duration of feeding bouts (s): the average duration of feeding bouts.

Number of social interactions within 1 m of the feeder: number of social tactile interactions the focal pig performed and received within 1 m of the feeder (i.e. pushing, head-to-head knock, anal nosing, levering, mounting, nose-to-body, nose-to-nose, parallel pressing, pushing, tail biting).

Displacements: the pig is displaced from the feeder by another pig.
Feeder occupancy over a 24 h period was measured by counting the number of pigs with their head in the feeder at 10 min intervals, at 10, 17 and 23 weeks of age.

**Growth performance**

Daily feed delivered for each pen was recorded using a computerised fully automatic feed delivery and weight recording system. A sensor in each feed bin was activated when feed levels fell below a certain level and feed was delivered and measured into the feed bin from the silo.

Pigs were weighed in pen lots at 10, 17 and 23 weeks of age. The average live weight was calculated, which was the total pen weight divided by the number of pigs in the pen.

Pigs were transported to the abattoir and held in lairage in unmixed pen groups. Carcass performance data and injury data were collected for all pigs. The data were collected by the author and a trained technician, at approximately 20 minutes after slaughter, once the carcass had been de-haired and the viscera and testicles removed. Carcass weight was measured and the carcass back fat was measured using a Hennesey-Chong probe (P2) at the P2 site, 60mm from the pig’s midline immediately posterior to the last rib. Dressing percentage was measured, and refers to the carcass weight/live weight of the pig, expressed as a percentage.

**Injury**

Non-infectious arthritis, stifle joint damage was scored as follows:

1 - no swelling, clear straw-coloured synovial fluid from all stifle joints when pricked.

2 - swelling in 1 to 2 stifle joints; thick bloody synovial fluid (non-infectious) emitted from joint when pricked.

3 - swelling in 3 to 4 stifle joints; thick bloody synovial fluid (non-infectious) emitted from joint when pricked.
Carcass bruising and scratching, as a result of transport and lairage, were scored as follows:

1 - no visible bruises or scratches.
2 - visible bruises and scratches on less than 50% of the carcass.
3 - visible bruises and scratches on greater than 50% of the carcass.

Carcass scalding, a result of constant contact with the litter at high temperature was scored as follows:

1 - scalding on 1 hind leg.
2 - scalding on 2 hind legs.

Statistical analysis

The effects of the two factors, pen space and feeder space, were analysed by analysis of variance using Minitab (Release 11 for Windows™, 1996) statistical software. The pen was the experimental unit and the source of variation is presented in Table 4.2.

Table 4.2 Source of variation for experimental design.

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>Degrees of freedom</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Factors</td>
<td></td>
</tr>
<tr>
<td>Pen space</td>
<td>1</td>
</tr>
<tr>
<td>Feeder availability</td>
<td>1</td>
</tr>
<tr>
<td>Interaction</td>
<td>1</td>
</tr>
<tr>
<td>Block</td>
<td>2</td>
</tr>
<tr>
<td>Error</td>
<td>6</td>
</tr>
<tr>
<td>Total</td>
<td>11</td>
</tr>
</tbody>
</table>

The care and use of pigs in this experiment conformed with the requirements of the Australian Prevention of Cruelty to Animals Act 1986 and the NHMRC “Australian code of practice for the care and use of animals for scientific purposes”.
RESULTS

There were no significant differences (P>0.05) due to the main effects, pen space and feeding space, on the activity as estimated by time spend standing and other behaviours such as locomotory behaviour, and social behaviour of pigs at 10 weeks of age (Table 4.3). There were also no significant (P>0.05) interactions between the main effects on these variables.

Table 4.3. The effects of pen space and feeding space on the activity and social behaviour (mean ± SED) of entire male growing pigs at 10 weeks of age.

<table>
<thead>
<tr>
<th></th>
<th>Pen space</th>
<th></th>
<th>Feeding space</th>
<th></th>
<th>SED</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unrestricted</td>
<td>Restricted</td>
<td>Unrestricted</td>
<td>Restricted</td>
<td></td>
</tr>
<tr>
<td>Postures^*:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standing</td>
<td>35.7</td>
<td>42.2</td>
<td>42.3</td>
<td>35.6</td>
<td>6.58</td>
</tr>
<tr>
<td>Sitting</td>
<td>0.4</td>
<td>1.8</td>
<td>1.5</td>
<td>0.7</td>
<td>0.66</td>
</tr>
<tr>
<td>Lying</td>
<td>63.9</td>
<td>56.0</td>
<td>56.2</td>
<td>63.7</td>
<td>6.71</td>
</tr>
<tr>
<td>Behaviours^+:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Idle</td>
<td>71.4</td>
<td>67.2</td>
<td>63.8</td>
<td>74.9</td>
<td>8.00</td>
</tr>
<tr>
<td>Locomotory</td>
<td>11.8</td>
<td>9.6</td>
<td>12.1</td>
<td>9.3</td>
<td>1.83</td>
</tr>
<tr>
<td>Pen tactile interactions</td>
<td>19.2</td>
<td>11.8</td>
<td>13.0</td>
<td>18.0</td>
<td>4.05</td>
</tr>
<tr>
<td>Social tactile interactions</td>
<td>13.0</td>
<td>19.7</td>
<td>19.4</td>
<td>13.2</td>
<td>2.22</td>
</tr>
<tr>
<td>Agonistic</td>
<td>2.0</td>
<td>1.8</td>
<td>2.2</td>
<td>1.5</td>
<td>0.88</td>
</tr>
<tr>
<td>Sexual</td>
<td>1.0</td>
<td>1.2</td>
<td>1.3</td>
<td>0.9</td>
<td>0.67</td>
</tr>
</tbody>
</table>

^ Postures and behaviours recorded as % of observation time and frequency, respectively.

There was a significant (P<0.05) effect of pen space on a number of the social behaviours at 17 weeks of age. Pigs with the restricted pen space had reduced (P<0.05) locomotory behaviour and increased social tactile interactions (P<0.05) compared to those with the unrestricted pen space (Table 4.4). There were no significant (P>0.05) main effects on the other behaviours observed in the pen. There were no significant (P>0.05) pen space x feeding space interactions.
Table 4.4. The effects of pen space and feeding space on the activity and social behaviour (mean ± SED) of entire male growing pigs at 17 weeks of age.

<table>
<thead>
<tr>
<th></th>
<th>Pen space</th>
<th></th>
<th>Feeding space</th>
<th></th>
<th>SED</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unrestricted</td>
<td>Restricted</td>
<td>Unrestricted</td>
<td>Restricted</td>
<td></td>
</tr>
<tr>
<td>Postures†</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standing</td>
<td>43.0</td>
<td>40.8</td>
<td>45.3</td>
<td>38.4</td>
<td>5.72</td>
</tr>
<tr>
<td>Sitting</td>
<td>0.9</td>
<td>2.1</td>
<td>2.3</td>
<td>0.7</td>
<td>0.75</td>
</tr>
<tr>
<td>Lying</td>
<td>56.1</td>
<td>57.1</td>
<td>52.4</td>
<td>60.9</td>
<td>5.72</td>
</tr>
<tr>
<td>Behaviours†</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Idle</td>
<td>68.7</td>
<td>72.3</td>
<td>66.3</td>
<td>74.7</td>
<td>16.99</td>
</tr>
<tr>
<td>Locomotory</td>
<td>12.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7.5&lt;sup&gt;b&lt;/sup&gt;</td>
<td>10.5</td>
<td>9.6</td>
<td>1.20</td>
</tr>
<tr>
<td>Pen tactile interactions</td>
<td>21.2</td>
<td>15.1</td>
<td>18.3</td>
<td>18.0</td>
<td>2.89</td>
</tr>
<tr>
<td>Social tactile interactions</td>
<td>14.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>31.5&lt;sup&gt;b&lt;/sup&gt;</td>
<td>25.5</td>
<td>20.5</td>
<td>1.94</td>
</tr>
<tr>
<td>Agonistic</td>
<td>0.8</td>
<td>1.1</td>
<td>0.7</td>
<td>1.3</td>
<td>0.26</td>
</tr>
<tr>
<td>Sexual</td>
<td>0.9</td>
<td>1.6</td>
<td>1.7</td>
<td>0.7</td>
<td>0.48</td>
</tr>
</tbody>
</table>

<sup>a, b</sup> Within rows, means with different superscripts are significantly different at P<0.05.

† Postures and behaviours recorded as % of observation time and frequency, respectively.

Pigs with the restricted pen space had increased social tactile interactions (P<0.05) compared to those with unrestricted space at 23 weeks of age (Table 4.5). There were no significant (P>0.05) main effects on the other behaviours observed in the pen and there were no significant (P>0.05) pen space x feeding space interactions.
Table 4.5. The effects of pen space and feeding space on the activity and social behaviour (mean ± SED) of entire male growing pigs at 23 weeks of age.

<table>
<thead>
<tr>
<th></th>
<th>Pen space</th>
<th>Feeding space</th>
<th>SED</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unrestricted</td>
<td>Restricted</td>
<td>Unrestricted</td>
</tr>
</tbody>
</table>
| Postures 
Standing      | 27.9            | 28.4           | 35.3          | 21.0        | 5.86 |
| Sitting                | 0.3             | 0.3            | 0.3           | 0.3         | 0.30 |
| Lying                  | 71.8            | 71.3           | 64.2          | 78.7        | 5.73 |
| Behaviours 
Idle         | 81.4            | 82.5           | 79.4          | 84.5        | 5.20 |
| Locomotory             | 8.0             | 7.1            | 8.9           | 6.2         | 1.80 |
| Pen tactile interactions| 11.2            | 9.9            | 12.5          | 8.6         | 3.21 |
| Social tactile interactions | 6.8\ a            | 23.4\ b         | 17.0          | 13.2        | 2.21 |
| Agonistic              | 0.9             | 0.4            | 0.9           | 0.5         | 0.41 |
| Sexual                 | 0.7             | 1.0            | 0.6           | 1.1         | 0.49 |

\a, \b Withins rows, means with different superscripts are significantly different at P<0.05.

+ Postures and behaviours recorded as % of observation time and frequency, respectively.

Pigs with the restricted pen space had significantly more (P<0.05) social tactile interactions around the feeder than pigs with unrestricted pen space at 10 weeks of age (Table 4.6). Pigs in the restricted feeding space had a higher (P<0.001) % of feeders occupied during the observation period. There were no significant (P>0.05) main effects on the other behaviours observed in the pen and there were no significant (P>0.05) interactions between main effects on the variables.
Table 4.6. The effects of pen space and feeding space on the feeding behaviour (mean ± SED) of entire male growing pigs at 10 weeks of age.

<table>
<thead>
<tr>
<th></th>
<th>Pen space Unrestricted</th>
<th>Pen space Restricted</th>
<th>Feeding space Unrestricted</th>
<th>Feeding space Restricted</th>
<th>SED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total time within 1 m of feeder (s)</td>
<td>5410</td>
<td>6729</td>
<td>6457</td>
<td>5681</td>
<td>410.12</td>
</tr>
<tr>
<td>Total time feeding (s)</td>
<td>2514</td>
<td>2650</td>
<td>3015</td>
<td>2149</td>
<td>259.88</td>
</tr>
<tr>
<td>Number of feeding bouts</td>
<td>33.3</td>
<td>38.3</td>
<td>39.2</td>
<td>32.4</td>
<td>4.49</td>
</tr>
<tr>
<td>Average duration of feeding bouts (s)</td>
<td>94.0</td>
<td>71.4</td>
<td>85.3</td>
<td>80.1</td>
<td>8.06</td>
</tr>
<tr>
<td>Average number of social tactile interactions within 1 m of the feeder</td>
<td>95.2\textsuperscript{a}</td>
<td>183.5\textsuperscript{b}</td>
<td>136.3</td>
<td>142.3</td>
<td>20.94</td>
</tr>
<tr>
<td>Displacements</td>
<td>9.2</td>
<td>11.1</td>
<td>11.8</td>
<td>8.5</td>
<td>0.95</td>
</tr>
<tr>
<td>Average % of feeders occupied during daylight hours (0540 h to 2000 h)</td>
<td>92.0</td>
<td>93.6</td>
<td>76.1\textsuperscript{c}</td>
<td>109.5\textsuperscript{f}</td>
<td>3.08</td>
</tr>
</tbody>
</table>

\textit{a, b, c, d, e, f} Within rows, means with different superscripts are significantly different at P<0.05, P<0.01 and P<0.001, respectively.

Pigs in the restricted feeding space had a higher (P<0.001) % of feeders occupied during the 23 hour observation period. There were no significant (P>0.05) main effects on the other behaviours observed in the pen and there were no significant (P>0.05) main effects or interactions between main effects on the feeding behaviour of pigs at 17 weeks of age (Table 4.7).
Table 4.7. The effects of pen space and feeding space on the feeding behaviour (mean ± SED) of entire male growing pigs at 17 weeks of age.

<table>
<thead>
<tr>
<th></th>
<th>Pen space</th>
<th>Feeding space</th>
<th>SED</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unrestricted</td>
<td>Restricted</td>
<td>Unrestricted</td>
</tr>
<tr>
<td>Total time within 1 m of feeder (s)</td>
<td>4697</td>
<td>3924</td>
<td>4982</td>
</tr>
<tr>
<td>Total time feeding (s)</td>
<td>2424</td>
<td>2075</td>
<td>2295</td>
</tr>
<tr>
<td>Number of feeding bouts</td>
<td>41.3</td>
<td>33.1</td>
<td>40.1</td>
</tr>
<tr>
<td>Average duration of feeding bouts (s)</td>
<td>64.9</td>
<td>66.5</td>
<td>61.6</td>
</tr>
<tr>
<td>Average number of social tactile interactions within 1 m of the feeder</td>
<td>172.6</td>
<td>196.0</td>
<td>193.3</td>
</tr>
<tr>
<td>Displacements</td>
<td>11.2</td>
<td>11.4</td>
<td>10.9</td>
</tr>
<tr>
<td>Average % of feeders occupied during day light hours (0540 h to 2000 h)</td>
<td>69.1</td>
<td>71.4</td>
<td>53.8\textsuperscript{e}</td>
</tr>
<tr>
<td>Average % of feeders occupied during night (2000 h to 0540 h)</td>
<td>20.1</td>
<td>23.8</td>
<td>10.9\textsuperscript{e}</td>
</tr>
</tbody>
</table>

\textsuperscript{a,b,c,d,e,f} Within rows, means with different superscripts are significantly different at P<0.05, P<0.01 and P<0.001, respectively.

Pigs with the restricted feeding space had a longer (P<0.05) average duration of feeding bouts than pigs with unrestricted feeding space at 23 weeks of age (Table 4.8). Pigs with restricted feeding space also had a higher (P<0.001) % of feeders occupied during the 23 hour observation period. There were no significant (P>0.05) main effects on the other behaviours observed at the feeder at 23 weeks of age, and there were no significant (P>0.05) interactions between the main effects.
Table 4.8. The effects of pen space and feeding space on the feeding behaviour (mean ± SED) of entire male growing pigs at 23 weeks of age.

<table>
<thead>
<tr>
<th></th>
<th>Pen space</th>
<th></th>
<th>Feeding space</th>
<th></th>
<th>SED</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unrestricted</td>
<td>Restricted</td>
<td>Unrestricted</td>
<td>Restricted</td>
<td></td>
</tr>
<tr>
<td>Total time within 1 m of feeder (s)</td>
<td>2773</td>
<td>2921</td>
<td>2762</td>
<td>2932</td>
<td>508.53</td>
</tr>
<tr>
<td>Total time feeding (s)</td>
<td>1620</td>
<td>1560</td>
<td>1546</td>
<td>1634</td>
<td>210.82</td>
</tr>
<tr>
<td>Number of feeding bouts</td>
<td>24.8</td>
<td>23.6</td>
<td>27.3</td>
<td>21.1</td>
<td>3.55</td>
</tr>
<tr>
<td>Average duration of feeding bouts (s)</td>
<td>70.3</td>
<td>69.5</td>
<td>57.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>82.4&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.70</td>
</tr>
<tr>
<td>Average number of social tactile interactions within 1 m of the feeder</td>
<td>59.5</td>
<td>61.6</td>
<td>71.1</td>
<td>50.0</td>
<td>9.80</td>
</tr>
<tr>
<td>Displacements</td>
<td>5.9</td>
<td>6.0</td>
<td>7.2</td>
<td>4.7</td>
<td>1.65</td>
</tr>
<tr>
<td>Average % of feeders occupied during day light hours (0540 h to 2000 h)</td>
<td>69.3</td>
<td>72.9</td>
<td>52.7&lt;sup&gt;c&lt;/sup&gt;</td>
<td>89.6&lt;sup&gt;f&lt;/sup&gt;</td>
<td>2.00</td>
</tr>
<tr>
<td>Average % of feeders occupied during night (2000 h to 0540 h)</td>
<td>19.2</td>
<td>16.5</td>
<td>10.7&lt;sup&gt;c&lt;/sup&gt;</td>
<td>25.0&lt;sup&gt;f&lt;/sup&gt;</td>
<td>1.36</td>
</tr>
</tbody>
</table>

<sup>a, b, c, d, e, f</sup> Within rows, means with different superscripts are significantly different at P<0.05, P<0.01 and P<0.001, respectively.

There was a similar feeder occupancy and group feeding pattern for the unrestricted and restricted pen space treatments at 10, 17 and 23 weeks of age (Figure 4.2, 4.3 and 4.4). There was no significant (P>0.05) difference between unrestricted and restricted pen space treatment on average the percentage of feeders occupied throughout the day between treatments (Table 4.6, 4.7 and 4.8).
Figure 4.2. Daily feeding pattern at 10 weeks of age. Percentage of feeders occupied in the unrestricted pen space (-•-) and restricted pen space (-■-) treatments. The cameras were moved from 11.30 to 12.30.

Figure 4.3. Daily feeding pattern at 17 weeks of age. Percentage of feeders occupied in the unrestricted pen space (-•-) and restricted pen space (-■-) treatments. The cameras were moved from 11.30 to 12.30.
Figure 4.4. Daily feeding pattern at 23 weeks of age. Percentage of feeders occupied in the unrestricted pen space (•••) and restricted pen space (■■■) treatments. The cameras were moved from 10.30 to 11.30.

The group feeding pattern was similar for both unrestricted and restricted feeder space at 10 weeks of age. Greater than 100 percent feeder space occupancy was observed when the pigs were 10 weeks of age because as the pig's heads and shoulders were smaller, more than two pigs could put their head in the feeder at any time (Figure 4.5).

Figure 4.5. Daily feeding pattern at 10 weeks of age. Percentage of feeders occupied in the unrestricted feeder space (•••) and restricted feeder space (■■■) treatments. The cameras were moved from 11.30 to 12.30.
There was a lower feeder occupancy in the unrestricted feeder space pens, however there was a similar group feeding pattern at 17 weeks of age (Figure 4.6).

![Graph showing daily feeding pattern at 17 weeks of age.](image)

**Figure 4.6.** Daily feeding pattern at 17 weeks of age. Percentage of feeders occupied in the unrestricted feeder space (---) and restricted feeder space (■) treatments. The cameras were moved from 10.30 to 11.30.

The daily feeder occupancy was lower (P<0.001) in the unrestricted feeder space pens compared to the restricted feeding spaces, however there was a similar group feeding pattern at 23 weeks of age (Figure 4.7).

![Graph showing daily feeding pattern at 23 weeks of age.](image)

**Figure 4.7.** Daily feeding pattern at 23 weeks of age. Percentage of feeders occupied in the unrestricted feeder space (---) and restricted feeder space (■) treatments. The cameras were moved from 11.30 to 12.30.
Pigs with the restricted feeding space had a higher (P<0.05) average daily intake and feed:gain ratio over their growth period from 10 to 23 weeks of age than pigs with the unrestricted feeding space (Table 4.8). There were no significant differences (P>0.05) due to the main effects on other growth variables measured. There were no significant (P>0.05) interactions between main effects on the growth variables.

Table 4.8. The effect of pen space and feeding space on the growth performance (mean ± SED) of entire male growing pigs at 10, 17 and 23 weeks of age.

<table>
<thead>
<tr>
<th></th>
<th>Pen space</th>
<th>Feeding space</th>
<th>SED</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unrestricted</td>
<td>Restricted</td>
<td>Unrestricted</td>
</tr>
<tr>
<td>Live weight (kg) at</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 weeks</td>
<td>24.3</td>
<td>24.4</td>
<td>24.3</td>
</tr>
<tr>
<td>17 weeks</td>
<td>67.3</td>
<td>67.1</td>
<td>67.1</td>
</tr>
<tr>
<td>23 weeks</td>
<td>104.8</td>
<td>104.0</td>
<td>104.6</td>
</tr>
<tr>
<td>ADG (kg/day) from</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10-17 weeks</td>
<td>0.807</td>
<td>0.802</td>
<td>0.805</td>
</tr>
<tr>
<td>17-23 weeks</td>
<td>0.828</td>
<td>0.807</td>
<td>0.825</td>
</tr>
<tr>
<td>10-23 weeks</td>
<td>0.815</td>
<td>0.805</td>
<td>0.815</td>
</tr>
<tr>
<td>ADI (kg/day) from</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10-17 weeks</td>
<td>1.77</td>
<td>1.71</td>
<td>1.64</td>
</tr>
<tr>
<td>17-23 weeks</td>
<td>2.41</td>
<td>2.42</td>
<td>2.38</td>
</tr>
<tr>
<td>10-23 weeks</td>
<td>2.08</td>
<td>2.05</td>
<td>2.00&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a</sup> <sup>b</sup> Within rows, means with different superscripts are significantly different at P<0.05

Carcass weight (P<0.001), carcass P2 back fat (P<0.001), dressing percentage (P<0.01) and average carcass bruising (P<0.01) were significantly lower in pigs with restricted pen space than those with unrestricted pen space (Table 4.9). There were no significant (P>0.05) main effects on average leg damage and scalding. There were no significant (P>0.05) interactions between main effects on the carcass characteristics.
Table 4.9. The effects of pen space and feeding space on carcass performance (mean ± SED) of entire male growing pigs at 23 weeks of age.

<table>
<thead>
<tr>
<th></th>
<th>Pen space</th>
<th>Feeding space</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unrestricted</td>
<td>Restricted</td>
</tr>
<tr>
<td>Carcass weight (kg)</td>
<td>78.3c</td>
<td>76.3d</td>
</tr>
<tr>
<td>Dressing %</td>
<td>74.8e</td>
<td>73.4d</td>
</tr>
<tr>
<td>Carcass P2 (mm)</td>
<td>12.5c</td>
<td>11.6f</td>
</tr>
<tr>
<td>Average bruising (1-3)</td>
<td>1.13c</td>
<td>1.09d</td>
</tr>
<tr>
<td>Average leg damage (1-3)</td>
<td>1.22</td>
<td>1.17</td>
</tr>
<tr>
<td>Scalding on 1 leg</td>
<td>3.17</td>
<td>3.33</td>
</tr>
<tr>
<td>(incidence)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scalding on 2 legs</td>
<td>0.30</td>
<td>0.00</td>
</tr>
<tr>
<td>(incidence)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Within rows, means with different superscripts are significantly different at P<0.05, P<0.01 and P<0.001, respectively.*

DISCUSSION

The hypothesis that longer but less frequent feeding bouts in deep-litter systems contribute to the poorer growth performance of pigs in deep-litter systems was in fact not tested in the current experiment. This was due to the fact that reduced pen and feeder space did not reduce the duration of feeding bouts and increase the frequency of feeding bouts. While social tactile interactions were both increased in the pen at 17 and 23 weeks of age with restricted pen space, and increased at the feeder at 10 weeks of age with restricted feeder access, feeding patterns (in terms of frequency and duration of feeding) were not affected by these two main effects.

Reducing space in the pen and feeding space in the present experiment failed to change the feeding behaviour in the direction of that seen in the conventional group housing system in Experiment 3. These present results suggest that the decrease in social interactions around the feeder observed in Experiment 3 was not responsible for the longer, less frequent feeding bouts observed in deep-litter pigs.
Another explanation for the differences observed in feeding behaviour between the two housing treatments in Experiment 3 may be related to possible disincentives for pigs in deep-litter, housing systems to visit the feeder. These disincentives may include large distance to travel to the feeders, reduced social facilitation to feed (due to greater distance from feeding pigs) and a reluctance to frequently visit the feeder due to increased opportunity to interact with a large number of pigs away from the feeder.

Animals make adjustments to their feeding behaviour as more effort is required to access feed. For example as it becomes harder to obtain feed, the frequency of feeding will decline. Food intake remains the same because compensatory increases occur in the size of the meal. Animals foraging in the natural environment visit fewer patches, but stay longer in each patch as a function of increasing travel time between patches (Johnson and Collier, 1994). Thus greater distance to the feeders in deep-litter systems may result in changes in feeding behaviour such as less frequent visits to the feeder, but of longer duration.

Pigs in small groups, such as conventionally-housed pigs, may have frequent but more shorter feeding bouts as a result of social facilitation (Hsia and Wood-Gush, 1983). A pig feeding is likely to have a greater effect on stimulating others to feed in smaller groups where pigs are in greater visual and auditory contact with group mates. Therefore in large groups as in the deep-litter system, pigs at large distances from the feeder are less likely to be stimulated by others feeding. Furthermore, the greater effort to move to the feeders to feed because of increased distances and the increased chance of interacting with a large number of pigs may reduce visits to the feeder in these large groups. These possible effects may result in the pigs in the deep-litter systems having less frequent, longer feeding bouts than those in the conventional system.

Spoolder et al. (1999) suggested that the increase in social pressure in larger groups of pigs may not wholly be related to just the cognitive aspects of pig behaviour, that is, attempting to maintain a stable social structure, but also related to increased competition for available resources. The authors suggested that even though theoretically the ratio of feeders to pigs is the same for smaller and larger groups of
pigs, there may be more competition in larger groups of pigs. Firstly, social facilitation (Hsia and Wood-Gush, 1983) may encourage large groups of pigs to want to feed at the same time. Secondly, dominant pigs may control the feeders and prohibit subordinates access to the feeder and finally pigs may have preferred feeding spaces. If this were the case, these three factors would increase the competition for feeding in large groups of pigs and could influence feeding behaviour. Perhaps pigs in the deep-litter treatment visited the feeder less frequently but for longer bouts compared to conventionally housed pigs because of an increase in competition that restricted feeder access. However, one interpretation of the reduced number of social interactions at the feeder in the deep-litter system in Experiment 3 is less competition at the feeders.

The only differences in feeding behaviour in the present experiment were a longer duration of feeding in the feeding space restricted pens at 23 weeks of age, which resulted in a higher daily intake and ultimately a poorer feed to gain ratio. The increase in feed intake was not reflected in an improved growth rate, therefore it can be assumed that there was a greater amount of feed wastage in the feeding space restricted treatments. The scientific literature suggests that the harder it is to obtain feed, the longer the pig will spend at the feeder once an opportunity to feed arises (Johnson and Collier, 1994). Pigs appear to spend more time feeding when offered fewer feeding places (Spoolder et al., 1999).

The daily feeding pattern of the pigs at 10, 17 and 23 weeks of age consistently showed that as expected, the groups with restricted feeder space had a greater percentage of feeder occupancy compared to those with unrestricted feeder space. The 23 hour feeding pattern at 17 and 23 weeks also show that there was a higher percentage of pigs feeding at night time in the groups with restricted feeder space. Higher feeding space occupancy supports the view that the increased feed:gain ratio for pigs in the restricted feeding space pens was at least partly a consequence of feed wastage.
Reduction in pen space resulted in pigs that were leaner and had a lower dressing percentage compared to pigs that had unrestricted pen space. Pigs with restricted pen space engaged in a greater number of social tactile interactions away from the feeder at 17 and 23 weeks of age, which may reflect greater social stress. While this effect on growth performance may be a consequence of stress, it appears unrelated to feeding behaviour. The increase in social pressure in the pigs with restricted pen space may have resulted in frequent activation of the sympathetic-adrenal medulla axis or the hypothalamic-pituitary adrenal axis.

Neuroendocrine responses such as elevated concentrations of catecholamines, ACTH and corticosteroids are known to have effects on growth performance (Bartov et al., 1980; Siegel and van Kampen, 1984; Metveit, 1984; Forbes, 1995; Dubeski et al., 1999), and thus social stress in the restricted pen space pens may have contributed to the leaner pigs with lower dressing percentage in these pens.

Locomotory behaviour was also significantly influenced by pen space when the pigs were 17 weeks of age. An explanation for the lack of effects at 10 and 23 weeks is that at 10 weeks there is considerable floor space in both treatments. As the pigs grew, the floor space was reduced, thus limiting locomotory behaviours, which was observed at 17 weeks in groups with restricted pen space. At 23 weeks, floor space was probably restricted in both treatments.

Carcass bruising and scratching was significantly reduced when pen space was restricted. Carcass scratching usually occurs during transport to the abattoir and at lairage prior to slaughter, possibly due to close confinement. An explanation for this decrease in bruising and scratching is that the pigs may have habituated more to close confinement with their pen mates. This possible increased tolerance of close confinement may lead to decreased activity and aggression during transport and lairage, and in turn a lower incidence of carcass bruising and scratching. There was no significant main effects on leg scalding and non-arthritic stifle joint damage.
In conclusion, the hypothesis that longer but less frequent feeding bouts results in poor pig growth performance of deep-litter pigs was not tested in Experiment 4. Increased social tactile interactions around the feeder do not appear to change feeding behaviour and ultimately improve growth performance of pigs in deep-litter systems. This may be due to the fact that the pen space and feeder space restrictions were not great enough to influence feeding behaviour, or in fact there was no effect. It is concluded that other factors are more likely to influence feeding behaviour and in turn growth performance of pigs in deep-litter systems. Possible disincentives to visit the feeder include increased distance to the feeders and increased social pressure.

However, results from this experiment show that pen floor space allowance is a potential factor that may affect growth performance in deep-litter, group housing systems. Pigs with unlimited pen space were fatter and had a greater dressing percentage than pigs with restricted pen space. An increase in social stress as a consequence of restricting pen space may result in leaner pigs with a lower dressing percentage.
EXPERIMENT 5. THE EFFECTS OF EXOGENOUS ACTH ON THE GROWTH PERFORMANCE, FAT MOBILISATION AND DISTRIBUTION AND ORGAN WEIGHT OF ENTIRE MALE GROWING PIGS.

INTRODUCTION
Experiment 4 studied the effect of restricted pen space and feeder availability on the growth performance and behaviour of entire male growing pigs in a deep-litter, group housing system. These two factors have the potential to influence social behaviour in a deep-litter system and thus were considered candidates to influence feeding behaviour and in turn growth performance. However, both reduced pen space and reduced feeder space failed to reduce the duration of feeding bouts and increase the number of feeding bouts. This suggested that if a change in feeding behaviour was responsible for the reduced growth performance of pigs in deep-litter systems, the social behaviour of pigs around the feeder was not implicated in this effect. It was concluded that other factors were therefore more likely to influence any feeding behaviour-induced changes in growth performance. For example distance to the feeder may be responsible for the changes observed in feeding behaviour and in turn changes in growth performance in deep-litter systems. This aspect requires further examination.

Another potential factor that may be responsible for reduced growth performance in deep-litter systems is social stress. Pigs in deep-litter systems engage in more social tactile interactions (Experiment 3). Neuroendocrine responses such as elevated concentrations of catecholamines (adrenaline), adrenocorticotropic hormone (ACTH) and corticosteroids are known to have effects on growth performance (Bartov et al., 1980; Siegel and van Kampen, 1984; Metveit, 1984; Forbes, 1995; Dubeski et al., 1999). Frequent social tactile interactions, such as that observed in Experiment 3 may activate the sympathetic-adrenal medulla (SAM) axis to secrete noradrenaline and adrenaline. Adrenaline mobilises glucose from glycogen in the liver and muscle glycogen via glycogenolysis (Bone, 1988), which provides a glucose source for the animal and prepares the animal to react spontaneously to the stressor (Metveit, 1984).
Cortisol concentrations remain elevated for several hours following a social challenge (Bradshaw et al., 1996). Therefore repeated challenges such as social tactile interactions could result in frequent elevated concentrations of cortisol. Corticosteroids have numerous effects, one of which is the effect on metabolic processes. Corticosteroids promote gluconeogenesis, which is the process of converting protein to glucose or glycogen from food or muscle (Bone, 1988). Noradrenaline and adrenaline also act directly upon fat cells and increase fat mobilisation (Bone, 1988) to provide metabolic fuel to sustain the stress response as well as other maintenance demands of the animal. As appetite is often depressed during stress the nutrient supply to support the increased metabolic and caloric demand is low and the difference is usually made up by catabolic processes that mobilise fat and protein (Elsasser et al., 2000).

The activation of the SAM and HPA axes can be monitored by measuring not only catecholamines and corticosteroids, but also by measuring some blood metabolites. Collection of blood within 30 seconds of commencement of sampling, enables measurement of basal concentrations of the blood metabolites unaffected by the stress of handling and blood collection. Non-esterified fatty acids (NEFAs) and glucose (source of glycerol) entry into the plasma pool reflects lipolysis and fat mobilisation respectively (Pethick and Dunshea, 1993). Plasma urea concentrations indicate protein catabolism. The adrenal gland under stress undergoes hyperplasia and increases in size and weight, and the capacity of the adrenal gland to secrete cortisol increases. This physiological change in the adrenal gland can be used as a measure of activation of the HPA axis.

There has been limited study of the stress physiology of pigs in deep-litter systems. Experiments conducted on broiler chickens, pheasants and rats (Bartov et al., 1980; Siegel and van Kampen, 1984) have shown that chronic treatment with corticosterone depressed weight gain, increased in food intake, increased fat deposition in the abdominal area and increased the weight of the liver. Dubeski et al. (1999) used ACTH to stimulate the pig to produce cortisol and showed that the adrenal glands were 42% heavier and the liver was 19% heavier in the ACTH treated pigs. These data suggest that when an animal is stressed, fat is mobilised and/or redistributed to the viscera and organ weights increase. Siegel and van Kampen (1984) showed that
exogenous corticosterone administration or stimulation of the adrenal glands resulted in slower growth and an increase in food consumption in young birds. Carcass data confirmed that protein deposition was reduced and fat deposition was increased. Similarly, corticosteroids administered to sheep and cattle increased fatness, although food intake was also increased (Forbes, 1995).

Stressors such as crowding (Cunningham, 1982), physical trauma (Richards, 1980) and unpleasant handling (Hemsworth et al., 1981) have been shown to reduce growth rate in young animals and live weight in mature animals. Hemsworth and Barnett (1991) and Klasing (1985) have shown that stressors such as these can adversely affect growth performance independent of effects on feed wastage.

The extent to which the impact of stress on physiological processes such as growth performance varies considerably in the scientific literature. The literature is unclear and somewhat contradictory. These inconsistencies suggest that our understanding of the stress response, particularly the magnitude of the stress response, on growth performance is poor. Obviously more research needs to be conducted on the stress physiology of pigs in deep-litter housing systems.

Industry records have shown that pigs in deep-litter systems are less efficient in converting feed to live weight gain and are fatter than conventionally housed pigs (Payne, 1997; Connor, 1995; Brumm, 1999; Honeyman et al., 1999; Payne et al., 2000). Social stress, as a consequence of unstable social hierarchies in large groups, may contribute to these growth performance problems. Experiment 5 therefore tested the hypothesis that frequently repeated or sustained elevations in plasma cortisol will result in depression in growth performance as seen in deep-litter systems. That is, increased feed intake, reduced growth, poorer feed:gain ratio and increased fat deposition will occur as a consequence of such stress. The influence of stress was simulated by treatment with daily injections of 100 IU of a slow-release depot of ACTH (Barb et al., 1982).
MATERIALS AND METHODS

Animals and housing

This experiment was conducted in an experimental facility in Corowa, New South Wales, Australia (36° latitude, 146.5° longitude). Thirty entire male growing pigs (Large White x Landrace) were individually housed indoors in pens measuring 2.4 x 0.9 m from 19 to 22 weeks of age. Commercial male finisher diet (13.7 MJDE, 14.7% crude protein and 0.5g/MJDE available lysine) in a pelleted form was fed to the pigs ad libitum in single-spaced, dry-feed feeders. The concrete pen floor was solid cement. The building was open-sided with natural ventilation. Shutters were positioned on two sides of the building and were automatically controlled with the use of a thermostat. The experiment was conducted during spring when the average daily temperatures ranged from a minimum of 10°C to a maximum of 20°C, with an average monthly rainfall of 67mm.

Growth performance

Eighty-five, 19 week-old entire male growing pigs were weighed and measured for back fat one week prior to the commencement of treatments. Back fat was measured at the P2 site, which is 60mm from the pig’s midline immediately posterior to the last rib, using a Toshiba SAL-32B real-time ultrasound with a PLB-508M 5MHZ linear array probe. Thirty pigs of similar weight and P2 measurement were selected from this pool of pigs and randomly allocated within weight strata to treatments.

Treatment means with respect to live weight and P2 back fat were similar for both treatments at 19 weeks of age (Table 5.3). Pigs were individually weighed daily while the treatment was imposed. P2 back fat was measured weekly throughout the experiment and average daily feed intake was also recorded. Final live weight and P2 back fat were measured the day before slaughter at 23 weeks of age. Leg fat was measured using a Toshiba SAL-32B real-time ultrasound with a PLB-508M 5MHZ linear array probe. The point of measurement was 60mm from the midline opposite the base of the tail.
Treatments

Two treatments commencing at 20 weeks of age were studied:

**ACTH** - The pigs were given daily intramuscular injections into the neck of 100 IU ACTH/ml (Synacthen® Depot-Novartis Pharmaceuticals Australia, NSW, Australia). A depot injection (slow release) was chosen to cause sustained elevated concentrations of cortisol (Barb et al., 1982).

**Control** - 1 ml of saline was administered daily to the pigs in the control treatment.

Treatments were imposed daily in a weighing crate at 0830 h for 21 days. For 1 week prior to commencing treatment, the pigs were trained by the experimenter to walk from their pen to an individual weighing crate by providing a feed reward (a sweet) in the crate. During the treatment period and following injections, the pigs were rewarded with sweets to minimise the aversiveness of the injections. A new needle was used for each injection to avoid injection site reactions.

Two pigs in the ACTH treatment were persistently difficult to move to the individual weighing crate. It was decided to move the pigs only into the aisle outside their pen and to inject them there, in order to minimise the stress associated with moving them to the individual weighing crate.

**Catheter insertion/collection of blood samples**

Ear vein catheters were inserted in five pigs per treatment on day 17 of treatment. The pigs were moved to the individual weigh crate. A snout-rope was applied to the pig’s nose and the insertion site (right ear) was cleaned with a 70% alcohol/chlorhex solution, coated with iodine and wiped dry using a sterile gauze swab. Xylocaine spray (topical anaesthetic) was sprayed onto the ear. A Secalon T central venous catheter was inserted into the ear and was secured by a single suture. The area was cleaned with iodine and alcohol/chlorhex solution. The pig’s ear was taped to the head with elastic adhesive bandage so that the catheter port was flush with the head.
The surgery was successful with catheters inserted within 5 minutes for each pig and blood sampling was successful in all of the 10 pigs at this time. An anticoagulant (heparanised saline, 100IU of heparin per ml of saline) was flushed through the catheter prior to and after blood sample collection. Pigs were housed individually with a spare pen on either side to eliminate other pigs from chewing the catheters and adhesive.

Pigs were checked every hour for 10 h after the ear vein catheters were inserted. Within 6 h of surgery, catheters were dislodged in two pigs. While this catheterisation technique had been used successfully in the past, it was apparent that the pigs could remove the catheters by rubbing their ears on the pen, or simply by shaking their heads during blood sampling. The following day, pigs were moved into the individual weigh crate where the catheters were examined. Six out of the ten catheters had dislodged over night. Two catheters were still intact, but not functioning and two catheters were viable. The decision was made to remove the catheters and to blood sample the pigs using jugular venipuncture.

Blood sampling via jugular venipuncture was conducted on five pigs per treatment on days 18 and 19 of treatment. Secretion of cortisol has a circadian rhythm (Griffith and Minton, 1991) and sampling was conducted in the afternoon when cortisol concentrations were expected to be at the lowest concentration. Blood metabolite levels would also be at their lowest concentration as most feeding activity occurs during the morning and evening (Dunshea et al., 1998). Blood samples were collected at 1300, 1400 and 1500 hours on days 18 and 19. The 10 pigs were blood sampled simultaneously by a team of experienced technicians, and sampling occurred within 1 minute for all 10 pigs. A snout-robe was placed around the pig’s nose to limit movement of the pig and an 8 ml blood sample was collected using a 10 ml sodium heparin VACUTAINER® (coating solution: 1000 IU/ml heparin in saline).
The blood samples were centrifuged at 2000 rpm for 10 minutes at 6°C. The plasma was harvested and stored at −20°C until analysis. The samples were analysed for porcine serum cortisol (total cortisol), non esterified fatty acids (NEFA’s), glucose, lactate and urea by the Endocrinology RIA Service at the Victorian Institute of Animal Science, Attwood, Australia.

**ACTH challenge**

The ACTH challenge was conducted at 1400 hours on day 19 of treatment. The 10 pigs that had been blood sampled previously were used. A snout-ropo was placed around the pig’s nose to limit movement of the pig and a 8 ml blood sample was collected as previously described. The pig was then given an intramuscular injection into the neck of 50IU/2ml ACTH (Synacthen® CIBA-GEIGY Australia Ltd., NSW, Australia). One hour after the ACTH injection, a second 8 ml blood sample was collected via jugular venipuncture.

The blood samples were centrifuged at 2000 rpm for 10 minutes at 6°C. The plasma was harvested and stored at −20°C until analysis. The samples were analysed for porcine serum cortisol (total cortisol) by the Endocrinology RIA Service at the Victorian Institute of Animal Science, Attwood, Australia.

**Behaviour – response to humans**

As there was so much daily handling and movement of pigs for daily injections, it was important not to confound the experiment with other stressors such as handling stress. The behavioural responses of pigs to the experimenter were assessed in a standard test (Hemsworth et al., 1996) when the pigs were 23 weeks of age.

The pigs were tested individually in a rectangular pen measuring 3 x 4.3 m in which the pigs were first given a two-minute familiarisation period. Six equal sized areas, approximately square in shape were drawn on the floor of the test pen, which enabled an assessment of locomotion during the familiarisation period to be made. After the familiarisation period, the experimenter entered the pen and stood immobile at the end of the pen. During the subsequent 3 minutes the following observations were made:
- time taken for the pig to approach within 0.5 m of the experimenter,
- total time spent within 0.5 m of the experimenter,
- time taken to first interact with the experimenter, and
- total number of interactions the pig made with the experimenter.

Carcass performance and organ weights

Pigs were slaughtered two days after the last treatment injection, at 23 weeks of age. Carcass performance data and organ weights were collected for each pig. Data were collected approximately 20 minutes after evisceration, once the carcass had been de-haired and the viscera and testicles removed. Carcass weight was measured using a scale and was measured as head on and prior to the removal of flare fat. The carcass P2 back fat was measured using a Hennesey-Chong probe (P2) at the P2 site. Dressing percentage was measured, and refers to the carcass weight/live weight of the pig, expressed as a percentage. Carcass leg fat depth was measured using an Intrascope at the point 4-6 cm from the tail and 2 cm from the midline above the second last lumbar vertebra. The digestive system, liver, spleen, kidneys, adrenal glands and visceral fat were collected and weighed.

The care and experimental use of pigs in this experiment conformed with the requirements of the Australian Prevention of Cruelty to Animals Act 1986 and the NHMRC “Australian code of practice for the care and use of animals for scientific purposes”.

Statistical Analysis

The data were analysed by analysis of variance using Minitab (Release 11 for Windows™-June 1996) statistical software. Pigs were the experimental unit and the source of variation examined is presented in Table 5.1

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>Degrees of freedom</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>1</td>
</tr>
<tr>
<td>Error</td>
<td>28</td>
</tr>
<tr>
<td>Total</td>
<td>29</td>
</tr>
</tbody>
</table>
RESULTS

Plasma cortisol concentrations were significantly (P<0.001) higher in the ACTH treatment. There was no significant (P>0.05) increase in the plasma concentrations of other blood metabolites measured (Table 5.2).

Table 5.2. Mean (± SED) plasma cortisol concentrations at 1400h and one hour after an ACTH challenge and the concentrations of NEFA’s, glucose, lactate and urea in the Control and ACTH treatments.

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>ACTH</th>
<th>SED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cortisol (nM) at 1400h</td>
<td>29.7e</td>
<td>303.5f</td>
<td>45.53</td>
</tr>
<tr>
<td>Cortisol (nM) at 1500 h, 1 h after an ACTH challenge</td>
<td>236</td>
<td>362</td>
<td>63.95</td>
</tr>
<tr>
<td>NEFA’s (umol/L)</td>
<td>155.4</td>
<td>161.3</td>
<td>26.77</td>
</tr>
<tr>
<td>Glucose (mmol/L)</td>
<td>5.2</td>
<td>5.7</td>
<td>0.33</td>
</tr>
<tr>
<td>Lactate (mmol/L)</td>
<td>1.9</td>
<td>2.2</td>
<td>0.45</td>
</tr>
<tr>
<td>Urea (mmol/L)</td>
<td>5.5</td>
<td>6.0</td>
<td>0.73</td>
</tr>
</tbody>
</table>

c, f Within rows means with different superscripts are significantly different at P<0.001.

Pigs in the ACTH treatment were significantly (P<0.05) heavier at 23 weeks of age and they had a higher (P<0.05) rate of gain and a higher (P<0.001) daily feed intake than pigs in the control treatment. The pigs in the ACTH treatment also had significantly higher (P<0.001) carcass fatness, as indicated by carcass P2 back fat and leg fat (Table 5.3).
Table 5.3. Mean (±SED) growth performance and carcass data of entire male growing pigs from 19 to 23 weeks of age in the Control and ACTH treatments.

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>ACTH</th>
<th>SED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Live weight at 19 weeks</td>
<td>77.4</td>
<td>77.4</td>
<td>1.38</td>
</tr>
<tr>
<td>Live weight at 22 weeks</td>
<td>106.4(^a)</td>
<td>111.5(^b)</td>
<td>2.41</td>
</tr>
<tr>
<td>Rate of Gain (kg/day)</td>
<td>1.1(^a)</td>
<td>1.3(^b)</td>
<td>0.07</td>
</tr>
<tr>
<td>Average Daily Intake (kg/day)</td>
<td>3.0(^c)</td>
<td>3.8(^f)</td>
<td>0.14</td>
</tr>
<tr>
<td>Feed:Gain</td>
<td>2.9</td>
<td>3.0</td>
<td>0.17</td>
</tr>
<tr>
<td>P2 (mm) at 23 weeks of age</td>
<td>10.9</td>
<td>12.5</td>
<td>0.87</td>
</tr>
<tr>
<td>Leg fat (mm) at 23 weeks of age</td>
<td>13.4</td>
<td>16.3</td>
<td>11.02</td>
</tr>
<tr>
<td>Carcass weight (kg)</td>
<td>81.5</td>
<td>84.4</td>
<td>1.79</td>
</tr>
<tr>
<td>Dressing %</td>
<td>76.6</td>
<td>75.8</td>
<td>0.51</td>
</tr>
<tr>
<td>Carcass P2 back fat (mm)</td>
<td>13.4(^c)</td>
<td>16.7(^d)</td>
<td>0.90</td>
</tr>
<tr>
<td>Carcass Leg fat (mm)</td>
<td>13.5(^c)</td>
<td>17.0(^d)</td>
<td>1.04</td>
</tr>
</tbody>
</table>

\(^a\), \(^b\), \(^c\), \(^d\), \(^e\), \(^f\) Within rows, means with different superscripts are significantly different at P<0.05, P<0.01 and P<0.001 respectively.

Pigs in the ACTH treatment had a significantly (P<0.01) heavier total viscera, heavier digestive system and more visceral fat. There was no significant (P>0.05) difference between treatments in other organ weights and adrenal glands (Table 5.4).

Table 5.4. Mean (±SED) weights of organs, adrenal glands and visceral fat of entire male growing pigs in the Control and ACTH treatments.

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>ACTH</th>
<th>SED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total viscera (kg)</td>
<td>9.7(^e)</td>
<td>10.6(^d)</td>
<td>0.29</td>
</tr>
<tr>
<td>Liver (kg)</td>
<td>2.11</td>
<td>2.21</td>
<td>0.06</td>
</tr>
<tr>
<td>Spleen (kg)</td>
<td>0.215</td>
<td>0.206</td>
<td>0.02</td>
</tr>
<tr>
<td>Kidneys (kg)</td>
<td>0.400</td>
<td>0.399</td>
<td>0.02</td>
</tr>
<tr>
<td>Digestive system-empty (kg)</td>
<td>7.3(^c)</td>
<td>8.2(^d)</td>
<td>0.27</td>
</tr>
<tr>
<td>Average adrenal gland (g)</td>
<td>4.19</td>
<td>4.37</td>
<td>0.38</td>
</tr>
<tr>
<td>Total visceral fat (kg)</td>
<td>0.65(^c)</td>
<td>1.0(^d)</td>
<td>0.12</td>
</tr>
</tbody>
</table>

\(^c\), \(^d\) Within rows, means with different superscripts are significantly different at P<0.01.
There was no significant (P>0.05) difference between the ACTH and Control treatments in the human test results (Table 5.5).

Table 5.5. Mean (±SED) human test data of entire male growing pigs in the Control and ACTH treatments.

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>ACTH</th>
<th>SED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exploration-number of areas entered</td>
<td>15.2</td>
<td>13.3</td>
<td>2.02</td>
</tr>
<tr>
<td>Time to approach experimenter (s)</td>
<td>57.0</td>
<td>55.4</td>
<td>20.9</td>
</tr>
<tr>
<td>Time to within 0.5m of experimenter (s)</td>
<td>25.0</td>
<td>29.7</td>
<td>12.1</td>
</tr>
<tr>
<td>Time to first interaction with experimenter (s)</td>
<td>87.6</td>
<td>100.1</td>
<td>26.5</td>
</tr>
<tr>
<td>Number of interactions with experimenter</td>
<td>3.9</td>
<td>2.3</td>
<td>1.3</td>
</tr>
</tbody>
</table>

**DISCUSSION**

Daily intramuscular injections of 100 IU slow-release ACTH-depot were successful in significantly elevating plasma cortisol concentrations in pigs compared to the control treatment. These results are consistent with other attempts to elevate plasma cortisol concentrations through the use of exogenous ACTH. Barb et al. (1982) increased plasma cortisol concentrations in pigs to an average of 300 nM with twice daily injections of a non-depot form of ACTH. In addition there was a trend for the plasma cortisol concentrations to be higher (P<0.09) 1 h after an ACTH challenge injection in the ACTH treated pigs. This suggests increased adrenal sensitivity to ACTH, however there was no evidence of hyperplasia of the adrenal glands.

In the present experiment, the ACTH treated pigs a higher significantly higher feed intake, were fatter at the carcass P2 back fat and leg fat sites and had more visceral fat and compared to the control pigs. These results are similar to those found by other authors.
Experiments conducted on broiler chickens, pheasants and rats (Dulin 1956; Bartov et al., 1980; Bartov, 1982; Simon, 1982; von Borell et al., 1992; Siegel and van Kampen, 1984) have shown that chronic treatment with corticosterone increased feed intake and fat deposition in the abdominal area. Forbes (1995) administered corticosteroids to sheep and cattle with the result of increased carcass fatness and feed intake.

However, contrary to other experiments (Dulin 1956; Bartov et al., 1980; Bartov, 1982; Simon and Leclercq, 1982; von Borell et al., 1992; Siegel and van Kampen, 1984), live weight gain was not significantly reduced in the ACTH treated pigs in the current experiment. In fact, the ACTH treated pigs had a higher rate of gain and were ultimately heavier than the control pigs. In previous findings where pigs were fearful of humans and were chronically stressed, growth rate was reduced (Hemsworth et al., 1981, 1985, 1987; Moberg, 1985). The extent to which the impact of chronic stress on physiological processes, such as growth performance, varies considerably between individuals and has been demonstrated in experiments conducted by Hennessy et al. (1988) and Turner (1998).

When the HPA axis of an animal is stimulated, energy is required to provide metabolic fuel to sustain the necessary physiological responses as well as other maintenance demands of the animal. As appetite is often depressed during stress, the nutrient supply to support the increased metabolic and caloric demand is low and the difference is usually made up by catabolic processes that mobilise fat and protein (Elsasser et al., 2000). While there were some limitations imposed by the collection technique, there was no significant difference observed in the present experiment between treatments in NEFAs, glucose, lactate and urea plasma concentrations. NEFA and glucose (source of glycerol) entry into the plasma pool reflects lipolysis and fat mobilisation respectively (Pethick and Dunshea, 1993), and plasma urea concentrations indicate protein catabolism.
Thus there is no evidence in the present experiment either in live weight loss and plasma urea concentration that protein and adipose tissue were being utilized more as an energy source in the ACTH treated pigs. However, pigs in the ACTH treatment had a higher daily feed intake. Therefore, it appears that the increase in feed intake in the ACTH treated pigs provided the metabolic fuel required to maintain the HPA axis. This speculation provides a possible explanation as to why pigs with less pen space in Experiment 4 had a lighter carcass weight and were leaner. It is possible that with restricted pen space, pigs were under greater stress as a result of an increase in social tactile interactions within the pen. The resultant increased metabolic demand in these pigs may not have been met by an opportunity to increase feed intake (e.g. increased social interaction in the pen may limit feeder access) and thus catabolism of protein and adipose tissue were utilized. The consequences with restricted pen space therefore were leaner pigs with a lower dressing percentage and increased visceral weight.

Pigs in deep-litter systems may have regular activation of the HPA axis as a result of an increase in social stress: it may be difficult to maintain a stable social organisation in large groups of pigs. As pigs in deep-litter systems appear to have unrestricted access to the feeder, as observed in Experiment 3, they may be able to increase their feed intake to fuel the increase in metabolic demand, and therefore they do not need to mobilise body reserves to provide energy for the physiological process. Therefore this may explain why pigs in deep-litter, group housing systems are fatter and have poorer growth performance.

Liver weight increases when an animal is stressed in order to increase capacity to produce glucose from glycogen in the liver (Metveit, 1984). There was no treatment effect on liver weight in the present experiment. This is contrary to that observed by Dubeski et al. (1999), who reported pigs with elevated concentrations of cortisol had a 19 percent heavier liver compared to control pigs. Experiments conducted by Dulin (1956), Bartov et al. (1980), Bartov (1982), Simon and Leclercq (1982), and Siegel and van Kampen (1984) have also shown that chronic treatment with corticosterone increases the weight of the liver. It is possible that there was no increase in liver weight in the present experiment as pigs were sourcing energy from higher feed intakes and did not need to source glucose from liver glycogen.
There was no significant difference in the average weight of the adrenal glands between the treatments. This result is surprising because if an animal is experiencing a chronic stress response, the adrenal gland is chronically hyperstimulated by ACTH and undergoes hyperplasia. The treatment period of 21 days of ACTH injections may have been insufficient for hyperplasia to be demonstrated. The pigs in the ACTH treatment had significantly heavier digestive tracts, possibly due to the increased feed intake. The size of the stomach and intestines may therefore have increased to cope with the increase in digesta through the gut. There were no significant differences in the human test, which indicates that the ACTH treated pigs did not become more fearful as a result of the treatment. These results also show that the experimental treatments were not confounded by other stressors such as fear of humans.

In conclusion, the results of the present experiment suggest that the growth performance problems seen in growing pigs in deep-litter, group housing systems may be related to the activation of the HPA axis. The activation of the HPA axis may be a consequence of an increase in social stress, such as the inability of pigs in large groups to maintain a stable social organization. As pigs in deep-litter systems appear to have unrestricted access to the feeder, as observed in Experiment 3, they may be able to increase their feed intake to fuel the increase in metabolic demand. This may be partly responsible for the growth performance problems seen in these systems. Obviously more research needs to be conducted on stress physiology of pigs in deep-litter, group housing systems and its implications on their growth performance.
GENERAL DISCUSSION

Deep-litter, group housing systems have been developed as an alternative method for raising pigs. These systems are cheaper to establish and are perceived as being "welfare- and "environmentally friendly compared to conventional confinement systems. However, recent industry records have shown that growing pigs raised in deep-litter housing systems have poor growth performance (Connor, 1995; Brumm, 1999; Honeyman et al., 1999; Payne et al., 2000). It is possible that these growth performance problems are related to the social and feeding behaviour and stress physiology of the pigs.

Therefore, the aim of this thesis was to investigate the social and feeding behaviour, stress physiology and growth performance of entire male growing pigs in deep-litter, group housing systems. The experiments in this thesis show conclusively that there are marked differences in the social and feeding behaviour of entire male growing pigs in deep-litter, group housing and conventional housing systems. These behavioural differences may influence pig growth performance, in terms of feed:gain ratio, back fat and carcass characteristics.

Experiment 1 defined an ethogram of behaviour of growing pigs in a deep-litter, group housing system. The social behaviours were pooled into the following behavioural categories: idle, locomotory, physical pen interactions, agonistic, sexual and social tactile interactions. The behaviours identified were similar to behaviours observed by Kelley et al. (1980), McGlone (1984, 1985) and Stolba and Wood-Gush (1989b) in growing pigs and by Jensen (1980,1982) in group-housed dry sows. This ethogram was used to quantify behaviours in successive experiments.

Experiment 2 studied the lying and locomotory behaviours of pigs, and the relationship to stifle joint damage of pigs raised in deep-litter, group housing systems. The results from this experiment showed that the majority of pigs do not have a preferred lying area in their pen and that stifle joint damage was not correlated to distance travelled within the pen. It was concluded that physical factors such as the condition of the deep-litter bedding are more likely to influence
stifle joint damage in pigs in deep-litter systems. The risk of stifle joint damage may increase if the deep-litter becomes boggy and the pigs have difficulty moving through the litter. This theory requires further investigation.

The social and feeding behaviour of pigs housed in deep-litter, group housing and conventional housing systems was studied in Experiment 3. There were marked differences in the social and feeding behaviour between entire male growing pigs in a deep-litter and those in conventional housing system. Pigs in the deep-litter system were more active, and had a higher frequency and duration of pen tactile interactions, social tactile interactions and sexual and agonistic behaviours. These results suggest that there may be a certain degree of social instability within larger groups of pigs on deep litter perhaps through an inability to individually recognise other pigs. Even though the pigs are housed in an enriched environment, they are spending considerably more time interacting with other pigs as well as with the physical features of the pen.

Observations of feeding behaviour of entire male growing pigs housed in a deep-litter system and a conventional system in Experiment 3 showed that pigs in the deep-litter housing system spent less time within 1 m of the feeder, had less feeding bouts and a longer duration of feeding compared to pigs in the conventional housing system. Pigs in the deep-litter housing system also had a lower frequency of social tactile interactions around the feeder than those in the conventional housing system, which may have caused less interruptions during feeding for pigs in the deep-litter housing system. Pen geometry may contribute to these differences in feeding behaviour. Pigs in the deep litter pens have more pen space compared to the conventional pens. Therefore pigs in the conventional pens may use the pen space around the feeder for non-feeding behaviours such as lying or social tactile interactions. This may create difficulties for pigs to gain and maintain feeder access in these pens.
One interpretation of the results in Experiment 3 is that pigs in the deep-litter housing system have relatively unrestricted feeding, which may have resulted in increased fat deposition and poorer feed:gain ratio because of changes in feeding patterns that affect feed utilisation. Experiment 4 aimed to test the hypothesis that the longer but less frequent feeding bouts in the deep-litter system may result in poorer growth performance. An attempt was made to reduce the frequency and duration of feeding bouts in a deep-litter system by increasing social tactile interactions around the feeder. Pen space allowance and feeding space have the capacity to influence the number of pig-to-pig interactions in a deep-litter housing system, and were these two factors were manipulated in Experiment 4.

Feeding behaviour was not changed as expected to a pattern similar to that seen in a conventional housing system (i.e. shorter but more frequent bouts) by restricting pen and feeding space. In fact, the feeding behaviour tended to move in the opposite direction. The average duration of feeding was increased in the pens with restricted feeding space (Table 6.1). The hypothesis that longer but less frequent feeding bouts results in poor growth performance of pigs in deep-litter housing systems therefore was not tested in Experiment 4. This was due to the fact that reduced pen space and feeding space did not change the feeding behaviour as expected by increasing social tactile interactions around the feeder. The level of restriction in the pen and feeder space may not have been severe enough to increase social tactile interactions or alternatively other factors were responsible for the differences in feeding behaviour between deep-litter and conventionally housed pigs.
Table 6.1. Feeding behaviour of entire male growing pigs at 23 weeks of age. Table includes data from Experiments 3 and 4.

<table>
<thead>
<tr>
<th></th>
<th>Experiment 3</th>
<th>Experiment 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pen space</td>
<td>Feeding space</td>
</tr>
<tr>
<td>Convent.</td>
<td>Deep-litter</td>
<td></td>
</tr>
<tr>
<td>Total time within 1 m of</td>
<td>6483&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3776&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>feeder (s)</td>
<td>2773</td>
<td>2921</td>
</tr>
<tr>
<td>Total time feeding (s)</td>
<td>1724</td>
<td>1554</td>
</tr>
<tr>
<td>Number of feeding bouts</td>
<td>52.9&lt;sup&gt;a&lt;/sup&gt;</td>
<td>30.5&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Average duration of</td>
<td>33.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>52.4&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>feeding bouts (s)</td>
<td>70.3</td>
<td>69.5</td>
</tr>
<tr>
<td>Number of social</td>
<td>37.8&lt;sup&gt;a&lt;/sup&gt;</td>
<td>17.0&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>tactile interactions</td>
<td>59.5</td>
<td>61.6</td>
</tr>
<tr>
<td>within 1 m of the feeder</td>
<td>71.1</td>
<td>50.0</td>
</tr>
</tbody>
</table>

<sup>a, b</sup> Within rows, means with different superscripts are significantly different at P<0.05.

Convent.: Conventional housing treatment
Unrest.: Unrestricted
Rest.: Restricted

It is concluded that there are other factors that are more likely to influence the feeding behaviour of pigs in deep-litter, group housing systems. These may include possible disincentives to visit the feeder such as increased distance to travel, increased social pressure and reduced social facilitation.

Animals make adjustments to their feeding behaviour as it more effort is required to feed. For example, as it becomes harder to obtain feed, the frequency of feeding will decline. Food intake remains the same because compensatory increases occur in the size of the meal. Thus pigs in large groups in deep-litter systems may reduce their feeder visits because of the extra effort required to visit the feeder. Pigs in the restricted feeding space pen in Experiment 4 also had a longer duration of feeding, which may reflect the extra effort required to feed due to increase pressure on the feeders. Lack of social facilitation may be responsible for the differences in
feeding behaviour observed in Experiment 2. The conventionally-housed pigs may have more frequent shorter feeding bouts as a result of social facilitation (Hsia and Wood-Gush, 1983). Whereas pigs in the deep-litter system may have reduced social facilitation because of the large distances from the feeder and the greater effort required to move through a large number of pigs to feed. These factors in deep-litter group housing systems may affect the feeding behaviour of pigs.

Of the two factors studied in Experiment 4, only pen space had a significant influence on growth performance. Pigs that had restricted space in the pen were leaner and had a lower dressing percentage compared to pigs that had unrestricted pen space. Pigs in the former pens engaged in a greater number of social tactile interactions, which may reflect greater social stress. Therefore, increased social stress in these pigs in pens with restricted pen space may have contributed to these growth effects. The scientific literature suggests that neuroendocrine responses are known to have effects on efficiency of growth, fat distribution, fat mobilisation and organ weights.

Large groups, as occurs in deep-litter systems, may reduce the ability of pigs to maintain stable social structures consequently increase both social tactile interactions (Experiment 3) and social stress. Experiment 5 tested the hypothesis that frequently repeated or sustained elevations in plasma cortisol will result in depressions in growth performance as seen in deep-litter, group housing systems. An increase in stress was simulated by treatment with daily intramuscular injections of 100 IU of ACTH. The pigs in the ACTH treatment were fatter at the carcass P2 backfat and leg fat sites, had more visceral fat, had a higher rate of gain and had a higher feed intake compared to the control treatment. It was concluded that the pigs in the ACTH treatment were able to fuel their increase in maintenance demands as a result of stress by increasing their feed intake.
This speculation provides an explanation for the growth performance differences observed in Experiment 4. The increase in social tactile interactions within the pens with restricted space may have caused an increase in social stress which resulted in activation of the HPA axis. Since feed intake may be limited in large groups by social factors, the increased metabolic demand was fueled by mobilization of fat and as a consequence pigs were leaner and had a lower dressing percentage. The results from Experiment 4 and 5 accentuate the fact that more rigorous research needs to be conducted on stress physiology of pigs in deep-litter, group housing systems.

The results from these experiments reported in this thesis have shown that there is a multitude of factors such as feeding and social behaviour and stress physiology that may influence the performance of entire male growing pigs in deep-litter, group housing systems. Clearly rigorous investigation is required to examine the effects of these factors, and to ultimately improve the growth performance of pigs in deep-litter, group housing systems.
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APPENDIX

Refereed publications and conference and seminar papers


