The Old School, Brewhouse Hill, Wheathampstead,
Hertfordshire AL4 8AN, UK

Animal Welfare 2006, 15: 119-130
ISSN 0962-7286

Motivation for group housing in gestating sows

RD Kirkden*† and EA Pajor

Department of Animal Sciences, Purdue University, Poultry Science Building, 125 South Russell Street, West Lafayette, IN 47907–2042, USA
† Present address: Animal Welfare Program, Faculty of Land and Food Systems, University of British Columbia, 2357 Main Mall, Vancouver, BC V6T 1Z4, Canada
* Contact for correspondence and requests for reprints: kirkden@interchange.ubc.ca

Abstract

It has been argued that the welfare of gestating sows is higher in groups than singly in stalls, in part because group housing offers them more space and social contact. This study set out to ascertain how important access to a group pen was to dominant sows housed in stalls, using a measure of motivation. Subjects were trained to perform a panel-pressing task, then housed in a stall and permitted each day to work for a day's access to a fully slatted group pen containing two familiar, subordinate sows at a stocking density of 2.7m² per pig. Social ranking was determined by observations at mixing and from feed competition tests. The fixed-ratio schedule was increased daily and the highest schedule reached (the reservation price) was used as a measure of motivational strength. To interpret this measure, it was compared with the highest schedule that subjects reached when working for access to the last 1/16th of their estimated ad libitum *daily food intake after having consumed the first 15/16ths free. Sixteen subjects were tested, eight working for access to the group pen first and eight for access to the food first. Seven subjects yielded useable data: four reached a higher schedule working for food and three reached a higher schedule working for the group pen. Overall, subjects attached no more importance to a day's access to the group pen than to the last 1/16th of their estimated* ad libitum *food intake. It is likely that the subjects were close to satiation when working for food because consumption frequently fell substantially short of the 'ad libitum' allowance. These results suggest that dominant, stall-housed sows are only weakly motivated to gain access to a fully slatted group pen, although motivation might be higher when deprived of access to the group pen for longer than one day, if tested at a different time of day or if the quality of the group space was improved; these three possibilities still need to be tested.*

Keywords: *animal welfare, housing, motivation, social contact, sows, space*

Introduction

It is estimated that 60–70% of sows in the US are housed in stalls throughout gestation (Barnett *et al* 2001). However, it is often argued that the welfare of sows is better in group housing systems, in part because of the increased space and social contact (Scientific Veterinary Committee 1997; Bracke *et al* 1999; Bracke *et al* 2002). Group housing is a general term used to describe a variety of housing systems that may differ in the method of food delivery, flooring, pen size and group size, but all group housing systems offer more space and social contact than stalls. In order to focus on these two factors, this study aimed to compare stalls with small, stable groups without straw bedding.

When comparing stall housing with group housing systems of this kind, the main welfare concerns are aggression in groups, versus the physical and behavioural restriction of stalls. Aggression mainly occurs at mixing (Meese & Ewbank 1973; Friend *et al* 1983; Dolf 1986; McGlone 1986; Luescher *et al* 1990) and when sows are competing for food (Csermely & Wood-Gush 1986; Edwards 1992; Gjein & Larssen 1995). The level of aggression at feeding time depends on the method of feeding and aggression can be substantially reduced by the use of feeding stalls (Edwards *et al* 1993; Barnett 1997; Andersen *et al* 1999). However, some aggression may also occur when competing for resources other than food, including preferred lying areas (Edwards 1992).

Gestation stalls severely restrict the sow's ability to move (Baxter & Schwaller 1983; Curtis *et al* 1989) and sows housed in stalls may develop decubitus ulcers (pressure sores) (Bäckström 1973; Gjein & Larssen 1995), which, in humans, are often painful (Freedberg *et al* 2003). It has also been suggested that an inability to exercise in stalls may lead to lameness (Marchant & Broom 1996); however, comparisons between stalls and small groups without straw have found no difference in the incidence of lameness (Morris *et al* 1997), perhaps because pigs perform little voluntary exercise when given additional space (Blackshaw & McVeigh 1986).

Gestation stalls also restrict the sow's ability to interact with other pigs. Sows housed in stalls have difficulty establishing stable dominance relations with their neighbours (Jensen 1984; Dolf 1986; Broom *et al* 1995) and it has been suggested, though not demonstrated, that this results in chronic stress. Stall-housed sows also spend less time

https://doi.org/10.1017/S0962728600030207 Published online by Cambridge University Press

performing social behaviour (Morris *et al* 1993), but it is not known whether this affects their welfare. Matthews and Ladewig (1994) attempted to measure motivational strength for social contact in individually housed growing pigs, but serious methodological concerns have been raised, including the very short duration and limited quality of contact permitted (Mason *et al* 1998; Jensen *et al* 2004), and the measure of motivation that was used (Kirkden *et al* 2003). Furthermore, Matthews and Ladewig (1994) were unable to quantify the value of social contact with any degree of precision, finding that it was worth more than a view of an empty pen but less than food. Barnett *et al* (1989) compared motivational strength for social contact between sows housed in groups and stalls by observing how they allocated their time in a choice test between food and social contact. Although they found no difference in motivational strength, the study revealed little about the motivation of sows to live in a group because the social contact was with unfamiliar sows.

Studies have consistently reported a higher incidence of stereotypy in stalls than in small groups without straw (Barnett *et al* 1985; Jensen 1988; Morris *et al* 1993; Vieuille-Thomas *et al* 1995; Pol *et al* 2002), but this finding is difficult to interpret. Stereotypies develop when an animal is frustrated (Mason 1991), but it is not clear whether physical confinement is the cause of the frustration. Lawrence and Terlouw (1993) have argued that hunger is the motivation underlying the development of stereotypy in sows and physical confinement merely shapes the sows' behaviour into a few simple and highly repetitive routines.

Physiological measures of stress have yielded contradictory findings, although mostly negative. Some studies have reported higher basal cortisol concentrations in sows in stalls compared with sows in small groups without straw (Barnett *et al* 1981; Barnett *et al* 1989 Experiment 1), but other studies have found no difference (Barnett *et al* 1985; Barnett *et al* 1989 Experiment 2; Barnett *et al* 1991; Nicholson *et al* 1993; Pol *et al* 2002). In addition, no difference has been found in the cortisol response to adrenocorticotropic hormone (ACTH) injection (Friend *et al* 1988; Von Borell *et al* 1992; Nicholson *et al* 1993), or in the status of the immune system (Von Borell *et al* 1992). The findings of most studies that stress levels are no higher in stalls than in groups might indicate that behavioural restriction in stalls does not cause significant frustration, or that the frustration caused by behavioural restriction is balanced by the stress caused by aggression in the group. It is also possible that the performance of stereotypy is a coping response that reduces physiological stress levels; however, studies investigating the relationship between stereotypy and cortisol concentration in sows have also produced contradictory findings (Cronin & Barnett 1987; Terlouw *et al* 1991; Von Borell & Hurnik 1991). Alternatively, the physiological data might be misleading, because it has been argued that basal cortisol concentrations and the cortisol response to ACTH injection are poor measures of chronic stress (Rushen 1991).

These studies present a rather confusing picture of the welfare benefits of group housing in sows. The development of decubitus ulcers in stalls, when this occurs, represents a clear welfare disadvantage of stall housing, but it remains unclear as to whether sows also suffer from frustration or stress as a result of physical and behavioural restriction. The sows' psychological state, as well as their health, needs to be evaluated to give a complete assessment of the housing systems.

A measure of the strength of sows' motivation for access to a group pen could help to clarify the picture in several ways. First, a measure of motivation would provide an estimate of the net value of the group pen environment. Positive factors, such as reduced physical and behavioural restriction, and negative factors, such as increased aggression, would both contribute to the sow's assessment of the group pen; therefore, a measure of motivation would give an idea of how the sow weighs up these qualitatively different variables. Second, when using measures of motivation it is relatively easy to ascertain which aspects of the environment the animal is responding to because the response is a programmed instrumental (goal-directed) act with well-defined consequences.

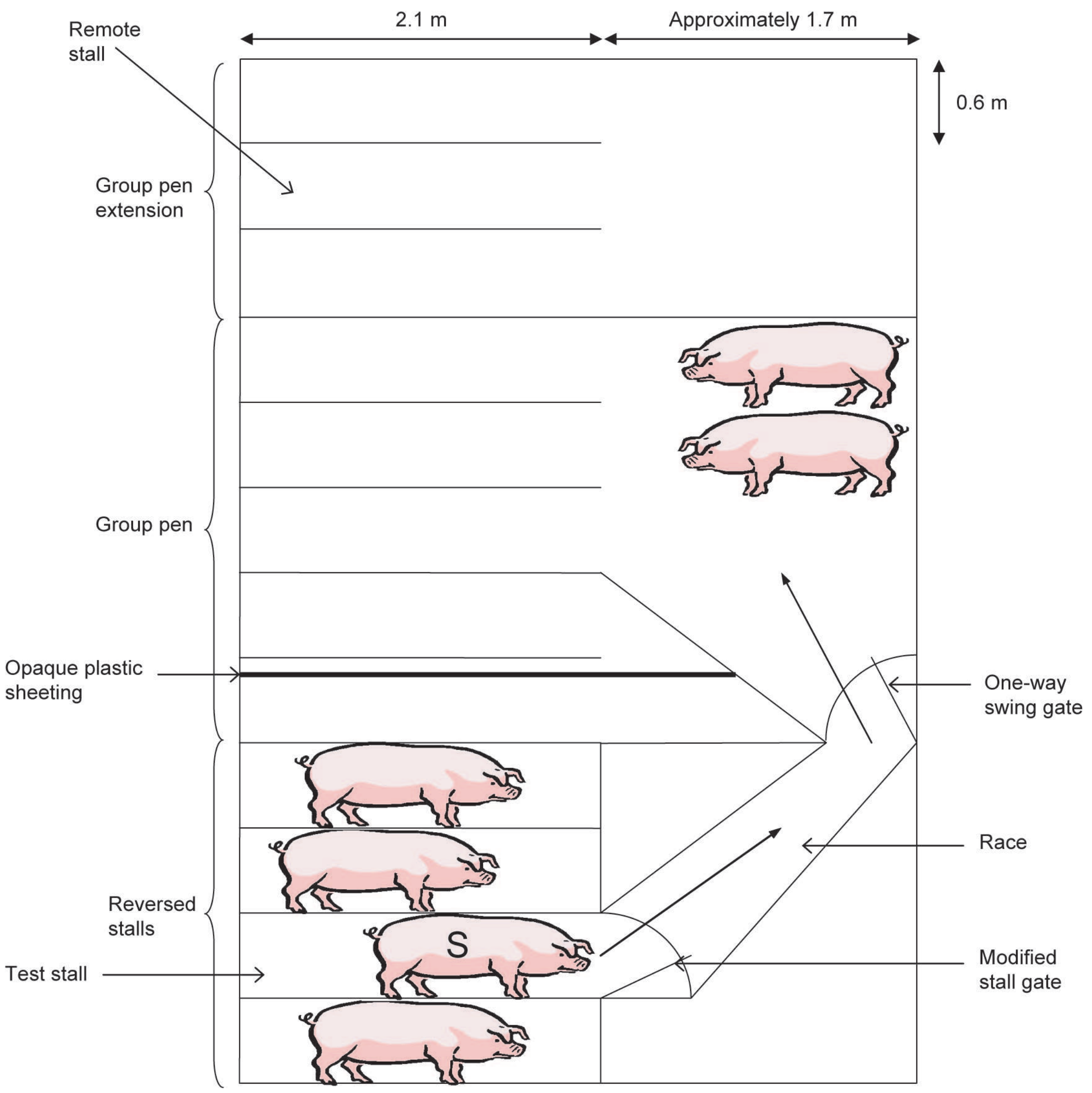
The objective of this study was to ascertain whether gestating sows housed in stalls were strongly motivated to gain access to a group pen containing familiar sows. Because social rank is likely to have a substantial effect on the quality of the group environment, it was necessary to distinguish dominant animals from subordinate animals; only dominant sows were used as subjects in this study because of a limited experimental period. It was reasoned that if motivation for the group pen was not strong in dominant sows then it would probably not be strong in lower ranking animals either (see Discussion).

In order to estimate the strength of an animal's motivation for a resource, it is necessary to compare the resource of interest with some other resource of known value — a comparator. Food is a suitable comparator because its value varies in a reliable manner — from very high to very low — depending on how much has already been eaten. If the willingness to pay for access to the resource of interest is equal to, or greater than the willingness to pay for access to food when hungry, the resource must be of substantial value to the animal. Conversely, if the willingness to pay for access to the resource is equal to, or less than the willingness to pay for access to food when close to satiation, the resource must be of little value.

Many previous studies have used food as a comparator but few have controlled the hunger level. Dawkins (1983), Duncan and Kite (1987), Olsson and Keeling (2002), and Cooper and Appleby (2003) compared the willingness to pay for a resource of interest with the willingness to pay for food after specific periods of food deprivation to obtain conclusions such as "hens paid as much for access to a nest box before laying as they did for food after 20 hours of food deprivation" (Duncan & Kite 1987); and "hens paid 75% as much for access to a perch at dusk as they did for food after 24 hours of food deprivation" (Olsson & Keeling 2002). In the present study, a variant on this approach was used. Instead of depriving subjects of food for a fixed period of time before measuring their willingness to pay, their food consumption during the course of the day was limited to a specific proportion of their daily *ad libitum* intake. Hunger can be understood either as a period of deprivation or as a degree of satiety, and either variable can be manipulated to

https://doi.org/10.1017/S0962728600030207 Published online by Cambridge University Press

Figure 1



The experimental arrangement to accommodate a group of six sows showing the route taken by the subject animal from the test stall to the group pen.

produce a scale of hunger. Hunger level at the time of testing was also confirmed retrospectively, by measuring the amount of food left uneaten at the end of the test period.

Materials and methods

Subjects

Ninety-six Yorkshire × Landrace sows were mixed, approximately 3–10 days after breeding, into 16 groups of six animals. All sows had previous experience of both group and stall housing.

Housing and apparatus

The experiment ran from September 2003 to May 2004. Temperature in the experimental building was maintained between 17°C and 29°C. Artificial lighting was provided between 0700h and 1900h each day, and the windows were blacked-out to minimise the amount of daylight that entered the building outside these hours.

The experimental building had a fully slatted floor and was fitted with two rows of gestation stalls, each stall measuring 0.6 × 2.1 m (width × depth). When the rear gates of the stalls were removed, they opened on to a 1.7 m deep pen area behind, permitting group pens to be created with full-length feeding stalls. In order to permit subjects to walk voluntarily from a gestation stall to a group pen (Figure 1), some of the stalls (bottom of figure) were turned around. A race led from the gate of one of the reversed stalls (the 'test stall') to a one-way swing gate, which opened into the group pen. The group pen accommodated three sows — including the subject animal — with a space allowance of 2.7 m^2 per sow. The pen could also be enlarged to a width of six feeding stalls, to accommodate a group of six sows. Four sets of

Table 1 Time schedule for subject animals working first for the group pen, then for food.

Day[1,2]	Location of subject	Procedure
T1–3	Group of 6	Familiarisation of all sows with each other. Observation of agonistic interactions on days 1–2. Feed competition test and weighing on day 3. Subject animal chosen.
T4–6	Group of 3	Familiarisation of subject animal with pen-mates. Observation of agonistic interactions on day 4. Feed competition test on day 6.
T7–8	Remote stall	Familiarisation with stall neighbours.
T9–10	Test stall	Familiarisation with test stall. Training to work for access to food in pen on day 10, FR1–15[3].
P1–2	Group of 3	Re-familiarisation with pen-mates. Observation of agonistic interactions on day 1.
P3–9	Various	Fed in remote stall at 0800h, then moved to test stall at 0930h. Operant test, working for access to group pen, 0930h–1030h, FR1. Left in chosen environment until 0800h the next day.
P10–X[4]	Various	As P3–9, except that FR increased daily.
PX+1	Various	As P3–9, FR1. Observation of agonistic interactions and feed competition test.
F1–10	Test stall	Measurement of *ad libitum* food intake, 0800h–1700h. Weighing on day 1.
F11–12	Test stall	On day 11, subject re-trained to work for access to food in pen at 0800h, FR1. On days 11–12, fed 15/16ths of estimated *ad libitum* intake, 0800h–1600h. Operant test, working for access to the last 1/16th in pen feeding stall, 1600h–1700h, FR1.
F13–Y[5]	Test stall	As F12, except that FR increased daily.
FY+1	Test stall	As F12, FR1. Weighing.

[1] T = Familiarisation and training phase of experiment; P = Working for group pen phase; F = Working for food phase.
[2] Day 1 was 3–5 days post-breeding. The experiment ended 46–49 days post-breeding.
[3] FR = Fixed ratio schedule: when a specific number of panel presses had been performed the latch holding the gate closed was released.
[4] X differed between subjects, ranging from day 12–13.
[5] Y differed between subjects, ranging from day 17–20.

Figure 2

The operant panel.

these apparatus were constructed in the building, permitting four groups of sows to be run simultaneously.

A group size of three sows was chosen in the group pen to maximise the likelihood that a social hierarchy would be established quickly and maintained throughout the experiment. In larger groups, spontaneous changes in the dominance order have been observed, typically among middle and low ranking pigs, more than one week after mixing (Meese & Ewbank 1973; Martin & Edwards 1994; Arey 1999). The space allowance is consistent with Whittemore's (1998) recommendation that sows should be allowed 1.0 m^2 per 100 kg body weight, which is increased when group size is small. It also conforms to the European Union Council Directive 2001/88/EC, which stipulates an area of 2.47 m^2 per sow when the group size is less than six.

At times when the subject animal was permitted to work for access to the group pen, the front gate of the test stall was replaced with a modified gate that had an operant panel attached above the trough (Figure 2). The modified gate was held shut by a solenoid-operated latch mechanism. When a specified number of panel presses had been performed (a fixed ratio [FR] schedule) the latch holding the gate closed was released. The subject animal was then able to push the stall gate open, walk along the race and push through the one-way swing gate into the group pen (Figure 3). Operation of the apparatus was controlled by a PC connected to a Switch and Sense 8 interface (Measurement Computing Corporation, Middleboro, MA, USA) running a program written in Visual Basic.

Black plastic sheeting was fixed between the reversed stalls and the group pen (Figure 1); in combination with the boards and the opaque swing gate (Figure 3), this prevented the subject animal from seeing into the group pen from the test stall, thereby minimising cues received from the group pen while working (Warburton & Mason 2003). A 51 × 102 mm (length × height) wire mesh was also attached to the sides of the test stall to prevent biting through the bars. This was done to control the subject's social environment in the test stall,

Table 2 Time schedule for subject animals working first for food, then for the group pen.

Day[1,2]	Location of subject	Procedure
T1–3	Group of 6	Familiarisation of all sows with each other. Observation of agonistic interactions on days 1–2. Feed competition test and weighing on day 3. Subject animal chosen.
T4	Group of 3	Familiarisation of subject animal with pen-mates. Observation of agonistic interactions and feed competition test.
T5	Remote stall	Familiarisation with stall neighbours.
T6	Test stall	Familiarisation with test stall. Training to work for access to food in pen, FR1–15[3].
F1–10	Test stall	Measurement of *ad libitum* food intake, 0800h–1700h.
F11–12	Test stall	Fed 15/16ths of estimated *ad libitum* intake, 0800h–1600h. Operant test, working for access to the last 1/16th in pen feeding stall, 1600h–1700h, FR1.
F13–Y[4]	Test stall	As F11–12, except that FR increased daily.
FY+1	Test stall	As F11–12, FR1.
FY+2	Test stall	Fed nothing for 24 h.
T1–3	Group of 6	Familiarisation of all sows with each other. Observation of agonistic interactions on days 1–2. Feed competition test and weighing on day 3.
T4–6	Group of 3	Familiarisation of subject animal with pen-mates. Observation of agonistic interactions on day 4. Feed competition test on day 6.
T7–8	Remote stall	Familiarisation with stall neighbours.
T9–10	Test stall	Familiarisation with test stall. Re-training to work for access to food in pen on day 10 at 0800h, FR1.
P1–2	Group of 3	Re-familiarisation with pen-mates. Observation of agonistic interactions on day 1.
P3–9	Various	Fed in remote stall at 0800h, then moved to test stall at 0930h. Operant test, working for access to group pen, 0930h–1030h, FR1. Left in chosen environment until 0800h the next day.
P10–X[5]	Various	As P3–9, except that FR increased daily.
PX+1	Various	As P3–9, FR1. Observation of agonistic interactions and feed competition test.

[1] T = Familiarisation and training phase of experiment; P = Working for group pen phase; F = Working for food phase.
[2] Day 1 was 3–10 days post-breeding. The experiment ended 56–65 days post-breeding.
[3] FR = Fixed ratio schedule: when a specific number of panel presses had been performed the latch holding the gate closed was released.
[4] Y differed between subjects, ranging from day 17–19.
[5] X differed between subjects, ranging from day 17–19.

because preliminary observations revealed that dominance relationships with neighbouring sows were disrupted by periods of absence from the test stall, which occurred when the subject was earning access to the group pen each day.

Experimental procedure

The experimental procedure consisted of three phases. Phase 1: selection, familiarisation and training of subjects. Phase 2: measurement of the willingness to pay for a day's access to the group pen. Phase 3: measurement of the willingness to pay for access to the last 1/16th of the estimated *ad libitum* daily food intake, after consuming the first 15/16ths free. In a cross-over experimental design, subjects from the first eight groups were scheduled to work first for access to the group pen (Table 1) and subjects from the remaining eight were scheduled to work first for access to the food (Table 2).

Phase 1: selection, familiarisation and training of subjects

Groups of six sows were mixed in the group pens. All agonistic interactions were recorded for 3–8 h on the day of mixing (day 1) and, if necessary, also on day 2. Aggressive interactions resulting in either retreat or in the submissive 'head tilt' behaviour were used to assess dominance relations, after Jensen (1984). On day 3, pairwise feed competition tests

Figure 3

A sow walking from the test stall to the group pen.

were carried out to obtain a second assessment of social ranking, following the procedure described by Marchant Forde (2002). Finally, one subject animal was selected from each group that was dominant to at least four other sows.

For the familiarisation procedure, the group of six sows was split-up. The size of the group pen was reduced to a width of three feeding stalls and the subject was placed in this pen with two subordinate sows, while the three remaining sows were housed in stalls. Of these three remaining animals, two later served as neighbours whenever the subject was housed in a stall; the third animal played no further part in the experiment, but remained housed in a reversed stall that was not adjacent to the test stall. The subject's social rank was re-assessed in the group of three by observing agonistic interactions on the day of re-grouping (day 4) and by feed competition tests on day 6, to check that it had not been altered by re-grouping. On day 7, the subject was transferred to a remote stall (Figure 1), with a subordinate neighbour on each side. On day 9, the subject was moved with two neighbours to the test stall and on day 10, the subject underwent training in this test stall. Subjects that were scheduled to work first for food received an abbreviated form of this procedure and were trained on day 6 (Table 2). Before working for access to the group pen, they received the full familiarisation procedure.

Subjects were trained to work for access to food rations in the group pen, while pen-mates were shut into feeding stalls. Each subject was trained in a single morning, before feeding. Food was initially smeared on the panel to initiate pressing; pushing through the two gates was trained by holding the gates open to a decreasing extent. At first most subjects found pushing through the one-way swing gate into the pen aversive, probably because it was opaque and weakly loaded to push back against them. However, the subjects completely overcame their aversion once they had learned that the gate yielded to their pushes. Once the subject was performing the task quickly and consistently on FR1, the schedule was increased to FR5, FR10 and FR15, at a rate of two or more trials per schedule, until the subject was performing multiple presses quickly. A brief session of re-training occurred later in the experiment when subjects were about to start working for their second resource type. Re-training occurred in the morning before feeding and consisted of three trials on FR1, working for access to food in the group pen.

Phase 2: measurement of the willingness to pay for access to the group pen

On the day after training, the subject was returned to the group pen and their social rank was re-assessed by observing agonistic interactions. Two days later, the subject was moved back to the test stall and permitted to work for access to the group pen. The procedure on this and subsequent days was as follows. The subject was fed at 0800h in a remote stall (see Figure 1) to avoid the development of an association between food and one of the housing environments. The level of aggression in the pens around feeding time was extremely low because of the presence of full-length feeding stalls, so removal of the subject from the pen at this time should not have affected the quality of the group environment. At 0930h, the subject was moved to the test stall and allowed up to 1 h to work. The subject remained in the chosen environment (the test stall or the group pen) until 0800h the following morning.

Subjects were permitted to work for seven days on a FR1 schedule, to give them time to learn that the reinforcer had changed from food to pen access. The schedule was then increased daily, following an ascending series (FR10, FR20, FR30, FR40, FR55, FR70, FR85, FR100, FR120, FR140 etc) until the subject failed to earn access to the group pen. The schedule on which the subject failed was repeated for a second day and if the subject failed again, the highest schedule completed was recorded as the reservation price for a day's access to the group pen. On the following day, the schedule was returned to FR1 to confirm that the subject was still motivated to gain access to the group pen. On this day, the subject's social rank was also re-assessed by observing agonistic interactions in the group pen and by feed competition tests.

Phase 3: measurement of the willingness to pay for access to food

For 10 days, the subject was housed in the test stall and allowed to eat *ad libitum* between 0800h and 1700h. The trough had a limited capacity but most of the food was consumed in the morning and it was possible to ensure an *ad libitum* intake by filling the trough three times before 1200h. Daily intake was measured and the last seven days' consumption was averaged to obtain an estimate of *ad libitum* intake. Previous studies have used 10 day (Lawrence *et al* 1989) and 14 day (Lawrence & Illius 1989) periods to estimate *ad libitum* food intake in boars. Preliminary observations showed that average intakes obtained in sows by day 10 were similar to those obtained by day 14.

The subject was then required to work once per day for access to the last 1/16th of the estimated daily food intake. The procedure was as follows. A quantity of food equal to 15/16^{ths} of the daily *ad libitum* intake was placed in the subject's trough between 0800h and 1200h, at the same times of day as when the subject had been fed *ad libitum*. At 1600h, the stall gate was replaced with the modified gate (Figure 2). Any food remaining in the trough of the stall gate was weighed and placed in the trough of the modified gate. The subject then had up to 1 h to work on the operant schedule for access to the last 1/16th of feed, which was located in one of the feeding stalls of the group pen; the subject's pen-mates were confined in the other two feeding stalls. If the subject gained access, then any food remaining in the trough of the modified gate was weighed and added to the food that the subject had earned in the trough of the feeding stall. The subject was deemed to have finished eating when no feeding had occurred for 10 min, at which point the subject was returned to the test stall and received no further food that day.

The subject was permitted to work for the first two days on a FR1 schedule. Then the schedule was increased daily, following the same series used in Phase 2, until the subject failed to earn access to the food. The schedule on which the subject failed was repeated for a second day and if the subject failed again, the highest schedule completed was recorded as the reservation price for food after consuming 15/16^{ths} of the estimated daily *ad libitum* intake. On the next day, the schedule was returned to FR1, to confirm that the subject was still motivated to gain access to the food.

Table 3 ***Ad libitum*** **food intakes and quantities left uneaten when working for food.**

Subject	Estimated *ad libitum* daily food intake in kg: mean (± SE)	Food uneaten as a % of estimated *ad libitum* daily intake: median (25th and 75th percentile)	Food uneaten as a % of quantity earned: median (25th and 75th percentile)
A2	7.1 (± 0.5)	0.8 (0.8, 1.4)	11.4 (9.3, 19.5)
B2	7.5 (± 0.3)	7.0 (4.9, 8.6)	70.0 (51.5, 88.5)
D2	7.4 (± 0.3)	4.6 (4.0, 6.6)	41.7 (40.0, 56.8)
C3	6.4 (± 0.2)	0.9 (0.4, 2.7)	12.5 (6.7, 28.6)
D3	7.3 (± 0.2)	12.2 (10.4, 13.6)	100.0 (98.2, 100)
D4	7.3 (± 0.5)	8.9 (3.0, 13.4)	83.3 (26.1, 99.3)
C5	9.5 (± 0.2)	18.8 (12.4, 21.0)	100.0 (100, 100)

Data analysis

To confirm that the subjects were aware that the reinforcer had changed from food to pen access during the seven preliminary trials on FR1 at the start of Phase 2, the latency of the subject to enter the pen — defined as the time elapsed between pressing the panel and pen entry — was measured during each trial. A General Linear Modelling (GLM) analysis was run to test within-subjects for linear and quadratic effects of trial number upon latency to enter the pen. Latency measures were log transformed to obtain a normal distribution. Because subjects were hungry during Phase 2, being fed only the standard sow ration, latency to enter the pen was expected to increase across trials as the sows learned that the resource had changed to pen access.

Reservation prices for the group pen and food were compared using *t*-tests for unequal variance, following a standard cross-over analysis procedure designed to distinguish the effects of resource type from those of testing period or resource order (Jones & Kenward 2003 p 21). The procedure simulated a split-plot ANOVA by using a series of three *t*-tests, thereby permitting the assumption of homogeneity of variance to be relaxed. The series of tests first checked between-subjects whether the effects of resource type and order were separable, then tested within-subjects for the simple effects of resource type and order of testing. Resource type and order were separable if the testing period had a similar effect upon the reservation price for access to the group pen as it had upon the reservation price for access to food.

Results

Valid motivational data were obtained from seven subjects: three working for access to the group pen first and four working for access to the food first. Data from the remaining groups of animals could not be used for the following reasons: no animal in the group was dominant to four others, so a suitable subject could not be chosen (one group); the subject lost dominant status during the experiment (two groups); the subject was apparently unable to regulate food intake (three groups); malfunction of the apparatus (two groups); and a methodological irregularity (one group). Three sows appeared to be unable to regulate their food intake and consumed as much food as was put in their troughs. Although more food was provided each day, the sows' intake continued to increase; when intake exceeded 11.5 kg the trials using these subjects were abandoned.

Visual inspection of the curves tracking *ad libitum* intake over time in the 12 subjects that were able to regulate food intake, indicated that consumption was in most cases fairly stable across the last 7 days, showing no clear directional trend, although fluctuations were sometimes quite large (the coefficient of variation was on average 11.1%). The *ad libitum* daily food intake for these animals was on average 7.4 ± 0.2 kg. Their average body weight when starting to eat *ad libitum* was 200 ± 9 kg, although food intake was not correlated with body weight ($r = 0.141$, n = 12, $P = 0.66$).

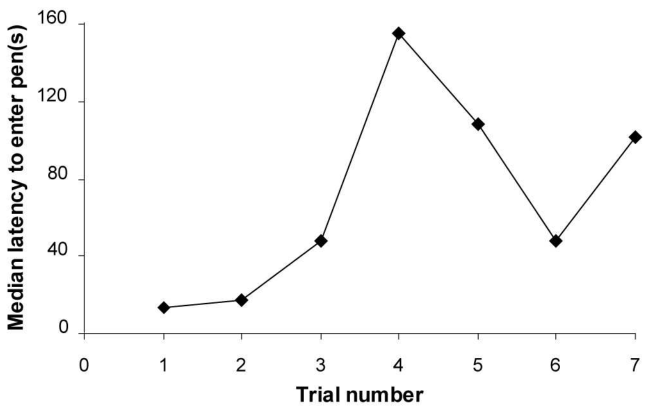
All seven subjects that yielded valid motivation data were dominant to their pen-mates and stall neighbours before working for access to the group pen, and maintained their dominant status in the group throughout the experiment. There was a very high level of agreement between the two methods used for assessing social rank, although the procedures focused on high ranking subjects; the social status of these individuals is often easier to discern. Subjects had a wide range of parities — ranging from 1 to 6 (mean = 2.9) — and body weights. Mean body weight was 203 ± 12 kg at the start of Phase 3 (eating *ad libitum*) and 218 ± 8 kg at the start of Phase 2 (working for access to the group pen).

The estimated *ad libitum* daily food intake for these seven subjects is shown in Table 3. The table also shows the median quantity of food left uneaten when the subjects worked for food, expressed either as a percentage of their estimated *ad libitum* intake or as a percentage of the food they earned (equal to 1/16th of their estimated *ad libitum* intake plus any food left uneaten in the trough of the test stall). It can be seen that total daily food consumption fell short of the estimated *ad libitum* intake (median shortfall: 7.0%) and that most subjects left a large proportion of the food they earned uneaten (median: 70.0%), indicating that most or all subjects were close to satiation when working for the last 1/16th of their estimated *ad libitum* intake.

The subjects' behaviour when gaining access to the group pen confirmed that the seven preliminary trials on FR1 were sufficient for them to learn that the reinforcer had changed from food to pen access. On the first trial, the subjects were expecting to receive a food reward and moved quickly through the race and into the group pen, as observed during training; median latency to enter the group pen was 13 s. However,

https://doi.org/10.1017/S0962728600030207 Published online by Cambridge University Press

Figure 4



The time course of changes in the median latency of hungry sows to enter the group pen after the reward in the group pen had changed from access to food (prior to trial 1) to access to two subordinate sows (trials 1–7). Latency to enter the group pen was defined as the time that elapsed between pressing the panel on a FR1 schedule and pen entry.

during the course of the next six daily trials, the median latency was substantially increased (Figure 4). The subjects walked more slowly and paused more frequently, interacting with the floor and walls of the race, and the swing gate. GLM analysis showed both linear ($F_{1,40}$ = 15.23, P = 0.0004) and quadratic ($F_{1,40}$ = 4.50, P = 0.040) effects of trial number upon latency to enter the pen, indicating that latency increased during the course of the seven trials and that on average it reached a maximum during day 4; median latency to enter the pen area on day 4 was 155 s and by day 7 it was 102 s.

Figure 5 shows the reservation prices obtained when subjects worked for a day's access to the group pen and when they worked for access to the last 1/16^th^ of the estimated *ad libitum* daily food intake, distinguishing test period 1 from test period 2. The effect that period, or resource order, had upon reservation price tended to be greater for access to the group pen than for access to food, but the difference was not significant (t_5 = 1.21, P = 0.29), indicating that the effect of resource type was separable from that of resource order. There was an order effect (t_5 = 3.61, P = 0.023): a higher price was paid for whichever resource was received second. However, when the order effect was taken into account, resource type had no effect on the reservation price (t_5 = 1.35, P = 0.25). The dotted lines (treatment means) show that the reservation price tended to be higher for access to food than for access to the group pen, but this difference was not significant.

Neither the reservation price for food, nor the reservation price difference — defined as the reservation price for the group pen minus the reservation price for food — was correlated with the quantity of food left uneaten, expressed either as a percentage of *ad libitum* intake (reservation price: r_s = –0.02, n = 7, P = 0.97; reservation price difference: r_s = 0.71, n = 7, P = 0.071), or as a percentage of food earned (reservation price: r_s = –0.06, n = 7, P = 0.90; reservation price difference: r_s = 0.74, n = 7, P = 0.058), although the reservation price difference showed a non-significant tendency to increase with both measures of food left uneaten.

Discussion

Ad libitum food intake was on average 7.4 ± 0.2 kg per day, which was 3.3 ± 0.1 times the sows' normal gestation ration of 2.3 kg per day and 4.1 ± 0.2 times their energy requirement for maintenance plus pregnancy (National Research Council 1998). This figure is consistent with a study by Bergeron *et al* (2000), in which multiparous Yorkshire × Landrace sows fed *ad libitum* consumed 7.2 ± 0.2 kg per day.

Three sows appeared unable to regulate their food intake, consuming more than 11.5 kg per day; *ad libitum* intake could not be ascertained, so these subjects were excluded from the study. It is unlikely that their exclusion affected the findings of the experiment. Among sows included in the study, there was no correlation between *ad libitum* food intake and motivation for access to food, defined either as the reservation price of food (r = 0.32, n = 7, P = 0.48), or as the reservation price difference (r = 0.25, n = 7, P = 0.59).

All experimental subjects, when offered 15/16^ths^ of their estimated *ad libitum* intake and required to work for the last 1/16^th^, consumed less food than they did when feeding *ad libitum*; there are two possible reasons for this. (1) They were reluctant to empty their troughs. Although all sows were capable of cleaning out their troughs, and invariably did so when fed their normal 2.3 kg daily ration, it is possible that they found it onerous to eat the last bits of food from the bottom and did not do so when feeding motivation was low. (2) Motivation to eat the last 1/16^th^ was lower when it was earned as a discrete ration late in the day than when it was available throughout the day and perhaps eaten as part of a larger meal. It is known that a positive feedback process increases feeding motivation during the course of a meal (Le Magnen 1971; Wiepkema 1971), whereas the effects of this feedback wane during periods of non-feeding (Houston & Sumida 1985; Haskell *et al* 1996).

It was apparent that feeding motivation was low when the last 1/16^th^ of feed was made available at 1600h. First, sows always had some uneaten food remaining in their troughs at this time. Second, when subjects earned access to the last 1/16^th^ they frequently ate little or none of it. In all cases some food was left uneaten in the trough at the end of the trial. Therefore, it seems reasonable to conclude that most subjects were close to satiation when working for the last 1/16^th^. Furthermore, the fact that the reservation price for food was not correlated with the quantity of food left uneaten indicates that subjects that left a small amount uneaten were not appreciably more hungry than subjects that left a large amount uneaten, suggesting that all subjects were close to satiation.

Because subjects often showed little interest in the food they earned, it is pertinent to ask whether they might have had other motives for operant responding besides feeding. Possible motives include monitoring a remote part of the environment and exercising a degree of control over the environment. Rats persist for more than 30 days in visiting the empty arms of a maze (Cowan 1977; Wilkie *et al* 1992) and this behaviour has been attributed to information gathering (Inglis *et al* 2001). Many species also exhibit

https://doi.org/10.1017/S0962728600030207 Published online by Cambridge University Press

'contrafreeloading', in which they choose to work for access to food when similar food is freely available, and may then fail to eat much of the earned food. This behaviour may also serve an information gathering function (Inglis *et al* 1997; Bean *et al* 1999). It has been suggested that animals are also motivated to exert control over positive aspects of their environments, although there is little empirical work to support this (Sambrook & Buchanan-Smith 1997). There is no evidence that these motivations are strong (Inglis *et al* 1997 indicate that 'contrafreeloading' occurs mainly when cost is low, occurring little at moderate FR levels), but they may support a low level of responding. Because the earned food was made available in the same location as the group pen, these motives would have had a similar effect upon responding for both reinforcers, with no net effect upon the relative value of the group pen.

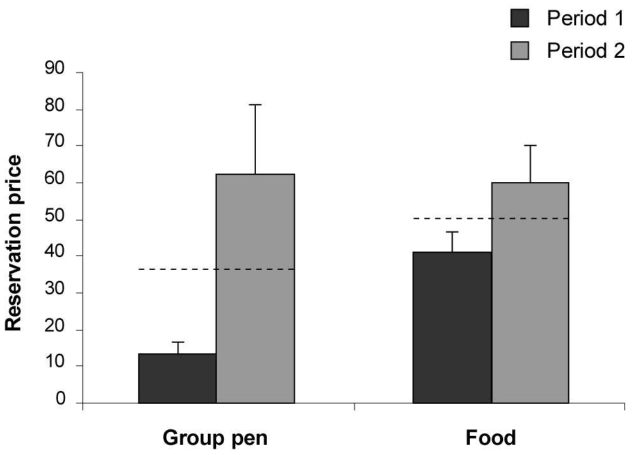
After working for access to food, sows passed through an open pen area on their way to the feeding stall, but showed no tendency to remain in this space. Mean latency to enter the feeding stall, after completing the operant schedule, was just 29 ± 5 s. Therefore, a preference for pen housing over stall housing is not considered to be a possible motive for the response in these trials.

When working for access to the group pen, subjects were clearly aware that the reward had changed from food to pen access. This was apparent from a marked decline in the rate at which they traversed the race for access to the group pen during the first few days of working on FR1 for pen access.

When the reservation prices were analysed, it was found that the order in which the two resources (the group pen and food) were made available affected the price that sows were prepared to pay for them. Most subjects paid a higher price for whichever resource they received second. The most likely reason for this effect of order is that subjects did not have sufficient experience with the series of operant schedules before testing. Schedules with a greater ratio requirement than FR1 are known as partial reinforcement schedules because not every response is rewarded. On an ascending series of FR schedules the rate of reinforcement declines across trials, approaching non-reinforcement, which is known as extinction. Therefore, the use of an ascending series of FR schedules effectively measures an animal's resistance to extinction. However, resistance to extinction is affected by training. Animals become more persistent in the face of non-reward when they have experience of responding on partial reinforcement schedules, a phenomenon known as the partial-reinforcement extinction effect (Domjan & Burkhard 1986 p 150). Psychological studies that have run animals repeatedly through an ascending series of FR schedules have found that the highest schedule completed is either constant (eg Roberts *et al* 1989; Czachowski *et al* 2003; Li *et al* 2003) or increasing (eg Ward *et al* 1996; Czachowski & Samson 1999) from one series to the next. Stable responding is typically achieved by running subjects through one or more dummy series before generating data for analysis.

Widowski and Duncan (2000) obtained a similar effect of order in hens. Instead of using an ascending series of FR schedules, Widowski and Duncan (2000) progressively increased the force required to make a single response, requiring subjects to push through a weighted door. Their subjects tended to pay a higher price for whichever of two resources they received second. In contrast, a study by Olsson *et al* (2002), in which the force requirement of a single response was also increased, found that hens paid a higher price in the first series of schedules than in the second. However, subjects were given free access to the reinforcer when they failed to complete the schedule at the end of the first series, which may have reduced their motivation to work in the second series.

Figure 5



Reservation prices for access to the group pen and access to the last 1/16th of daily *ad libitum* food intake, in test period 1 and test period 2. The reservation price is defined as the highest FR schedule completed for access to a resource and has no units.

It is logically possible that some change in the environment, such as ambient temperature, was responsible for the effect of order; however, this is unlikely to have been the case. Although daily temperature readings were not obtained, subjects were evenly balanced with respect to season. Two subjects (A2 and B2) that received pen access first in the autumn were balanced with two subjects (D4 and C5) that received food first in the spring. The remaining subjects, one having received pen access first (D2) and two having received food first (C3 and D3), all worked in the winter.

Although the order in which the resources were presented affected the reservation price, the effects of resource type were separable from those of resource order. It was found that the reservation price for a day's access to the group pen was no greater than the reservation price for access to the last 1/16th of the estimated *ad libitum* daily food intake. Because most or all of the subjects were close to satiation when working for the last 1/16th, it follows that motivation for a day's access to the group pen was no greater in dominant sows than motivation for food when close to satiation; in other words, motivation for a day's access to the group pen was low.

Several qualifications must be appended to this statement. (1) Subjects were deprived of access to the group pen for no longer than one day during the period of operant testing. Motivation might have been higher in sows housed in stalls

https://doi.org/10.1017/S0962728600030207 Published online by Cambridge University Press

for longer periods. Sows in commercial units are normally housed continuously in stalls for most of their gestation, a period of approximately 16 weeks. (2) Subjects worked for pen access in the morning and might have exhibited a higher motivation later in the day. When sows are allowed to move freely between stalls and a communal lying area throughout the day, in an un-bedded enclosure, the proportion of time spent in the communal area has been found to be higher during the night (H Vermeer, personal communication). Time spent in the communal area was also higher in winter than in summer, suggesting that ambient temperature was a factor, although, as in the present study, the temperature did not fall below 18°C. (3) Only dominant sows were tested. It is reasonable to expect that if motivation for access to a group pen is not strong in dominant sows, it will not be strong in lower ranking animals either. There is evidence that the welfare of lower ranking sows is poorer than that of dominant animals. In small, static groups with feeding stalls, low ranking individuals exhibit higher injury levels than dominant animals in the first month after mixing (O'Connell *et al* 2003), spend less time feeding (Andersen *et al* 1999), and have a lower farrowing rate and smaller litters (Nicholson *et al* 1993). The reduced pregnancy rate and litter size could be mediated by increased fear or stress (Kongsted 2004). It has been argued that motivational strength for access to resources reflects the perceived quality of the resources (Dawkins 1990) and it follows that motivation for access to a group pen is likely be no stronger in low ranking sows than in dominant sows. However, this hypothesis has not been tested empirically, so the findings for dominant sows must be extrapolated to lower ranking animals with caution. (4) The group pen was rather small and bare. It permitted full social contact and locomotion, but little else. There was sufficient space for all three sows to lie down simultaneously in the communal area, but they tended to compete for preferred lying places. The space allowance is consistent with regulations for the group housing of sows in the EU, but EU systems must also incorporate a solid concrete lying area and access to a manipulable material for the performance of foraging activities (European Directives 2001/88/EC and 2001/93/EC). It may be that such modifications to the environment, some of which are only possible in a group housing system (eg the provision of straw, which would block the drainage system beneath the slatted floors of stalls), would increase the sows' motivation for access to the group pen.

Conclusions and animal welfare implications

This study provides no evidence that stall-housed gestating sows perceive the increased social contact and space offered by a group pen to be important. However, further research needs to be carried out to ascertain whether increasing the period of prior confinement in the stall, increasing the quality of the pen environment, or altering the time of day at which the sow has access to the pen increase the perceived value of the group pen. It also needs to be confirmed that low-ranking sows do not attach more value to a group pen than dominant sows.

Acknowledgements

We would like to thank Bob Brown for building the apparatus, Dawn Haines for help running the experiment and the following other people for their technical assistance and advice: Paul Anderson, Dick Byrd, Erik Dekker, Tony Dickinson, Gilbert Gordon, Brock Ladd, Junior Lyman, Fritz Peacock, Jim Powlen, Scott Radcliffe, Carol Reisert, Brian Richert, Dan Weary and Sophia Wilcox.

References

Andersen IL, Bøe KE and Kristiansen AL 1999 The influence of different feeding arrangements and food type on competition at feeding in pregnant sows. *Applied Animal Behaviour Science 65*: 91-104

Arey DS 1999 Time course for the formation and disruption of social organisation in group-housed sows. *Applied Animal Behaviour Science 62*: 199-207

Bäckström L 1973 Environment and animal health in piglet production: a field study of incidences and correlations. *Acta Veterinaria Scandinavica Suppl 41*: 1-240

Barnett JL 1997 Modifying the design of group pens with individual feeding places affects the welfare of pigs. In: Bottcher RW and Hoff SJ (eds) *Livestock Environment V, Volume II* pp 613-618. ASAE: St Joseph, MI, USA

Barnett JL, Cronin GM and Winfield CG 1981 The effects of individual and group penning of pigs on total and free plasma corticosteroids and the maximum corticosteroid binding capacity. *General and Comparative Endocrinology 44*: 219-225

Barnett JL, Hemsworth PH, Cronin GM, Jongman EC and Hutson GD 2001 A review of the welfare issues for sows and piglets in relation to housing. *Australian Journal of Agricultural Research 52*: 1-28

Barnett JL, Hemsworth PH, Cronin GM, Newman EA and McCallum TH 1991 Effects of design of individual cage-stalls on the behavioural and physiological responses related to the welfare of pregnant pigs. *Applied Animal Behaviour Science 32*: 23-33

Barnett JL, Hemsworth PH, Newman EA, McCallum TH and Winfield CG 1989 The effect of design of tether and stall housing on some behavioural and physiological responses related to the welfare of pregnant pigs. *Applied Animal Behaviour Science 24*: 1-12

Barnett JL, Winfield CG, Cronin GM, Hemsworth PH and Dewar AM 1985 The effect of individual and group housing on behavioural and physiological responses related to the welfare of pregnant pigs. *Applied Animal Behaviour Science 14*: 149-161

Baxter MR and Schwaller CE 1983 Space requirements for sows in confinement. In: Baxter SH, Baxter MR and MacCormack JAC (eds) *Farm Animal Housing and Welfare* pp 181-199. Martinus Nijhoff: Boston, MA, USA

Bean D, Mason GJ and Bateson M 1999 Contrafreeloading in starlings: testing the information hypothesis. *Behaviour 136*: 1267-1282

Bergeron R, Bolduc J, Ramonet Y, Meunier-Salaün MC and Robert S 2000 Feeding motivation and stereotypies in pregnant sows fed increasing levels of fibre and/or food. *Applied Animal Behaviour Science 70*: 27-40

Blackshaw JK and McVeigh JF 1986 The behaviour of tethered sows when given the opportunity to exercise. *Proceedings of the Australian Society of Animal Production 16*: 147-150

Bracke MBM, Metz JHM, Spruijt BM and Dijkhuizen AA 1999 Overall welfare assessment of pregnant sow housing systems based on interviews with experts. *Netherlands Journal of Agricultural Science 47*: 93-104

Bracke MBM, Metz JHM, Spruijt BM and Schouten WGP 2002 Decision support system for overall welfare assessment in pregnant sows B: validation by expert opinion. *Journal of Animal Science 80*: 1835-1845

Broom DM, Mendl MT and Zanella AJ 1995 A comparison of the welfare of sows in different housing systems. *Animal Science 61*: 369-385

Cooper JJ and Appleby MC 2003 The value of environmental resources to domestic hens: a comparison of the work-rate for food and for nests as a function of time. *Animal Welfare 12*: 39-52

Cowan PE 1977 Systematic patrolling and orderly behaviour of rats during recovery from deprivation. *Animal Behaviour 25*: 171-184

Cronin GM and Barnett JL 1987 An association between plasma corticosteroids and performance of stereotypic behaviour in tethered sows. In: Barnett JL, Batterham ES, Cronin GM, Hansen C, Hemsworth PH, Hennessy DP, Hughes PE, Johnston NE and King RH (eds) *Manipulating Pig Production* p 26. Australasian Pig Science Association: Werribee, Australia

Csermely D and Wood-Gush DGM 1986 Agonistic behaviour in grouped sows. 1. The influence of feeding. *Biology of Behaviour 11*: 244-252

Curtis SE, Hurst RJ, Gonyou HW, Jensen AH and Muehling AJ 1989 The physical space requirement of the sow. *Journal of Animal Science 67*: 1242-1248

Czachowski CL and Samson HH 1999 Breakpoint determination and ethanol self-administration using an across-session progressive ratio procedure in the rat. *Alcoholism: Clinical and Experimental Research 23*: 1580-1586

Czachowski CL, Legg BH and Samson HH 2003 Assessment of sucrose and ethanol reinforcement: the across-session breakpoint procedure. *Physiology & Behavior 78*: 51-59

Dawkins MS 1983 Battery hens name their price: consumer demand theory and the measurement of ethological 'needs'. *Animal Behaviour 31*: 1195-1205

Dawkins MS 1990 From an animal's point of view: motivation, fitness, and animal welfare. *Behavioral and Brain Sciences 13*: 1-61

Dolf C 1986 Agonistic behaviour of dry sows in single stalls and group housing with special reference to the risk of resulting lesions. *Applied Animal Behaviour Science 15*: 193-194 (Abstract)

Domjan M and Burkhard B 1986 *The Principles of Learning and Behavior*, 2nd Edition. Brooks/Cole: Pacific Grove, CA, USA

Duncan IJH and Kite VG 1987 Some investigations into motivation in the domestic fowl. *Applied Animal Behaviour Science 18*: 387-388

Edwards SA 1992 Scientific perspectives on loose housing systems for dry sows. *Pig Veterinary Journal 28*: 40-51

Edwards SA, Brouns F and Stewart AH 1993 Influence of feeding system on the welfare and production of group housed sows. In: Collins E and Boon C (eds) *Livestock Environment IV* pp 166-172. ASAE: St Joseph, MI, USA

Freedberg IM, Eisen AZ, Wolff K, Austen KF, Goldsmith LA and Katz SI (eds) 2003 *Fitzpatrick's Dermatology in General Medicine, Volume I*, 6th Edition. McGraw-Hill: New York, USA

Friend TH, Knabe DA and Tanksley TD 1983 Behavior and performance of pigs grouped by three different methods at weaning. *Journal of Animal Science 57*: 1406-1411

Friend TH, Taylor L, Dellmeier GR, Knabe DA and Smith LA 1988 Effect of confinement method on physiology and production of gestating gilts. *Journal of Animal Science 66*: 2906-2915

Gjein H and Larssen RB 1995 Housing of pregnant sows in loose and confined systems — a field study. 1. Vulva and body lesions, culling reasons and production results. *Acta Veterinaria Scandinavica 36*: 185-200

Haskell MJ, Terlouw EMC, Lawrence AB and Erhard HW 1996 The relationship between food consumption and persistence of post-feeding foraging behaviour in sows. *Applied Animal Behaviour Science 48*: 249-262

Houston A and Sumida B 1985 A positive feedback model for switching between two activities. *Animal Behaviour 33*: 315-325

Inglis IR, Forkman B and Lazarus J 1997 Free food or earned food? A review and fuzzy model of contrafreeloading. *Animal Behaviour 53*: 1171-1191

Inglis IR, Langton S, Forkman B and Lazarus J 2001 An information primacy model of exploratory and foraging behaviour. *Animal Behaviour 62*: 543-557

Jensen MB, Pedersen LJ and Ladewig J 2004 The use of demand functions to assess behavioural priorities in farm animals. *Animal Welfare 13, Suppl*: S27-S32

Jensen P 1984 Effects of confinement on social interaction patterns in dry sows. *Applied Animal Behaviour Science 12*: 93-101

Jensen P 1988 Diurnal rhythm of bar-biting in relation to other behaviour in pregnant sows. *Applied Animal Behaviour Science 21*: 337-346

Jones B and Kenward MG 2003 *Design and Analysis of Cross-Over Trials*, 2nd Edition. Chapman & Hall/CRC: Boca Raton, FL, USA

Kirkden RD, Edwards JSS and Broom DM 2003 A theoretical comparison of the consumer surplus and the elasticities of demand as measures of motivational strength. *Animal Behaviour 65*: 157-178

Kongsted AG 2004 Stress and fear as possible mediators of reproduction problems in group housed sows: a review. *Acta Agriculturae Scandinavica, Section A, Animal Science 54*: 58-66

Lawrence AB and Illius AW 1989 Methodology for measuring hunger and food needs using operant conditioning in the pig. *Applied Animal Behaviour Science 24*: 273-285

Lawrence AB and Terlouw EMC 1993 A review of behavioral factors involved in the development and continued performance of stereotypic behaviors in pigs. *Journal of Animal Science 71*: 2815-2825

Lawrence AB, Appleby MC, Illius AW and MacLeod HA 1989 Measuring hunger in the pig using operant conditioning: the effect of dietary bulk. *Animal Production 48*: 213-220

Le Magnen J 1971 Advances in studies on the physiological control and regulation of food intake. *Progress in Physiological Psychology 4*: 203-261

Li N, He S, Parrish C, Delich J and Grasing K 2003 Differences in morphine and cocaine reinforcement under fixed and progressive ratio schedules; effects of extinction, reacquisition and schedule design. *Behavioural Pharmacology 14*: 619-630

Luescher UA, Friendship RM and McKeown DB 1990 Evaluation of methods to reduce fighting among regrouped gilts. *Canadian Journal of Animal Science 70*: 363-370

Marchant JN and Broom DM 1996 Effects of dry sow housing conditions on muscle weight and bone strength. *Animal Science 62*: 105-113

Marchant Forde JN 2002 Piglet- and stockperson-directed sow aggression after farrowing and the relationship with a pre-farrowing, human approach test. *Applied Animal Behaviour Science 75*: 115-132

Martin JE and Edwards SA 1994 Feeding behaviour of outdoor sows: the effects of diet quantity and type. *Applied Animal Behaviour Science 41*: 63-74

Mason GJ 1991 Stereotypies: a critical review. *Animal Behaviour 41*: 1015-1037

Mason GJ, McFarland D and Garner J 1998 A demanding task: using economic techniques to assess animal priorities. *Animal Behaviour 55*: 1071-1075

Matthews LR and Ladewig J 1994 Environmental requirements of pigs measured by behavioural demand functions. *Animal Behaviour 47*: 713-719

McGlone JJ 1986 Influence of resources on pig aggression and dominance. *Behavioural Processes 12*: 135-144

Meese GB and Ewbank R 1973 The establishment and nature of the dominance hierarchy in the domesticated pig. *Animal Behaviour 21*: 326-334

Morris JR, Hurnik JF, Friendship RM, Buhr MM and Allen OB 1993 The behavior of gestating swine housed in the Hurnik-Morris system. *Journal of Animal Science 71*: 3280-3284

Morris JR, Hurnik JF, Friendship RM, Buhr MM, Evans NM and Allen OB 1997 The effect of the Hurnik-Morris system on sow locomotion, skin integrity and litter health. *Journal of Animal Science 75*: 308-310

National Research Council 1998 *Nutrient Requirements of Swine*, 10th Edition. National Academy Press: Washington DC, USA

Nicholson RI, McGlone, JJ and Norman RL 1993 Quantification of stress in sows: comparison of individual housing versus social penning. *Journal of Animal Science 71, Suppl 1*: 112 (Abstract)

O'Connell NE, Beattie VE and Moss BW 2003 Influence of social status on the welfare of sows in static and dynamic groups. *Animal Welfare 12*: 239-249

Olsson IAS and Keeling LJ 2002 The push-door for measuring motivation in hens: laying hens are motivated to perch at night. *Animal Welfare 11*: 11-19

Olsson IAS, Keeling LJ and McAdie TM 2002 The push-door for measuring motivation in hens: an adaptation and a critical discussion of the method. *Animal Welfare 11*: 1-10

Pol F, Courboulay V, Cotte J-P, Martrenchar A, Hay M and Mormède P 2002 Urinary cortisol as an additional tool to assess the welfare of pregnant sows kept in two types of housing. *Veterinary Research 33*: 13-22

Roberts DCS, Loh EA and Vickers G 1989 Self-administration of cocaine on a progressive ratio schedule in rats: dose-response relationship and effect of haloperidol pretreatment. *Psychopharmacology 97*: 535-538

Rushen J 1991 Problems associated with the interpretation of physiological data in the assessment of animal welfare. *Applied Animal Behaviour Science 28*: 381-386

Sambrook TD and Buchanan-Smith HM 1997 Control and complexity in novel object enrichment. *Animal Welfare 6*: 207-216

Scientific Veterinary Committee 1997 *The Welfare of Intensively Kept Pigs. Report to the Directorate General XXIV of the European Commission.* Adopted 30th September 1997. Doc XXIV/ScVc/0005/97. Scientific Veterinary Committee, Animal Welfare Section: Brussels, Belgium

Terlouw EMC, Lawrence AB, Ladewig J, De Passillé AM, Rushen J and Schouten WGP 1991 Relationship between plasma cortisol and stereotypic activities in pigs. *Behavioural Processes 25*: 133-153

Vieuille-Thomas C, Le Pape G and Signoret JP 1995 Stereotypies in pregnant sows: indications of influence of the housing system on the patterns expressed by the animals. *Applied Animal Behaviour Science 44*: 19-27

Von Borell E and Hurnik JF 1991 Stereotypic behavior, adrenocortical function, and open-field behavior of individually confined gestating sows. *Physiology & Behavior 49*: 709-713

Von Borell E, Morris JR, Hurnik JF, Mallard BA and Buhr MM 1992 The performance of gilts in a new group housing system: endocrinological and immunological functions. *Journal of Animal Science 70*: 2714-2721

Warburton HJ and Mason GJ 2003 Is out of sight, out of mind? The effects of resource cues on motivation in the mink (*Mustela vison*). *Animal Behaviour 65*: 755-762

Ward AS, Li DH, Luedtke RR and Emmett-Oglesby MW 1996 Variations in cocaine self-administration by inbred rat strains under a progressive-ratio schedule. *Psychopharmacology 127*: 204-212

Whittemore CT 1998 *The Science and Practice of Pig Production*, 2nd Edition. Blackwell Science: Oxford, UK

Widowski TM and Duncan IJH 2000 Working for a dustbath: are hens increasing pleasure rather than relieving suffering? *Applied Animal Behaviour Science 68*: 39-53

Wiepkema PR 1971 Positive feedbacks at work during feeding. *Behaviour 39*: 266-273

Wilkie DM, Mumby DG, Needham G and Smeele M 1992 Sustained arm visiting by nondeprived, nonrewarded rats in a radial maze. *Bulletin of the Psychonomic Society 30*: 314-316

https://doi.org/10.1017/S0962728600030207 Published online by Cambridge University Press