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The effects of housing on heart rate of gestating sows during specific behaviours

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Abstract

The heart rates of 21 sows in three different dry sow housing systems were measured during feeding, drinking, rooting and lying with eyes open. Measurements were made on sows kept in: (1) a large group of 37 with an electronic sow feeder ($n = 7$); (2) small groups of five, with individual feeders ($n = 7$); (3) individual stalls ($n = 7$). For all three systems, heart rate was highest during feeding and lowest during lying, with rooting and drinking intermediate. When comparing between systems, stall-housed sows had significantly higher basal heart rates (54.1 b.p.m.) and average feeding heart rates (118.5 b.p.m.) than sows from large-group (45.9 b.p.m. and 105.9 b.p.m.) and small-group housing systems (46.7 b.p.m. and 102.5 b.p.m.). The variability of heart rate during feeding and the difference between average feeding heart rate and basal heart rate was also highest in stall-housed sows. Sows housed in the small group had higher mean peak heart rates during feeding than sows housed in the large group with stall-housed sows intermediate. Long-term confinement in stalls may induce a greater sympathetic nervous response to important stimuli such as feeding. However, a feeding environment in which there can be contact between sows results in higher mean peak feeding heart rates and heart rate variability probably due to short-term adrenal responses to agonistic interactions. © 1997 Elsevier Science B.V.

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1. Introduction

Heart rate is acknowledged as a useful indicator of an animal's internal state (Fraser and Broom, 1990). Factors which influence heart rate include individual identity,

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seasonality, stage of gestation and behaviour. Effects of behaviour on heart rate have been demonstrated in humans (Smith and Kampine, 1980), pigs (Marchant et al., 1995), sheep (Baldock et al., 1988), red deer (Price et al., 1993) and chicks (Potter, 1987) and are due to a physical or motor component, such as posture or locomotion, together with a psychological component which depends on perceptions of stimuli and preparation for future action. Examples of stimuli which may induce a psychological response include those from feeding (Baldock et al., 1988), social interaction (Marchant et al., 1995), handling (Price et al., 1993) or transport (Baldock and Sibly, 1990). In most cases, these stimuli have an effect which is additive to the physical component.

Heart rate responses to feeding have been recorded in several species including pigs, which show a rise in heart rate and blood pressure when feeding occurs (Houpt et al., 1983, Schouten et al., 1991). However, the feeding response is influenced by the housing system in which the pigs are kept and Schouten et al. (1991) have demonstrated a higher heart rate response to feeding in sows which were individually confined, compared with sows which were individually loose-housed.

With confined housing systems for gestating sows banned in the UK from 1st January 1999, producers are having to convert to systems in which the sows are kept in groups. A potential problem for group housing systems is ensuring that the sow's nutritional requirements are met, and a number of feeding methods are currently both in use and in development. The feeding method can have a large influence on aggression (Edwards et al., 1993), especially if the sows are fed as a group rather than individually, and may therefore influence the psychological response to feeding and, over the long term, influence the sows' welfare.

The aims of our study were: (1) to determine the effects of specified behaviours such as feeding, drinking, rooting and lying, on the heart rate of gestating sows; (2) to determine if there were any significant differences in heart rate during specified behaviours between sows housed long term in one of three different dry sow housing systems.

2. Methods

2.1. Subjects, housing and care

The subjects were 21 Large White × Landrace sows of similar genetic stock (Masterbreeders UK Ltd, Tring, UK). They had been assigned to different housing systems as gilts, for a long-term study investigating the effects of housing system on welfare. They were always returned to the same dry sow system after farrowing and were between 3.5 and 4 years of age at the time of the experiment. There was no policy of culling on the basis of poor reproductive performance, so the sows used in this experiment remained representative of the original populations assigned to each system.

Seven sows were housed in each of three adjacent rooms of identical design externally but modified internally to accommodate one of three different dry sow housing systems. The three groups of seven were matched for parity (mean $\pm$ s.e. = 7.05

$\pm$ 0.18), weight (mean $\pm$ s.e. = 273.3 $\pm$ 21.7 kg) and stage of gestation (mean $\pm$ s.e. = 48.1 $\pm$ 9.4 days after service).

1. Stalls ($n = 7$ from 11 confined sows). Individual conventional gestation stalls (2.0 m $\times$ 0.6 m) in which the sows were confined. Water was available ad libitum from a nipple drinker above the feed trough in each stall.
2. Small groups ($n = 7$ from three groups of five sows). Groups of five sows housed in identical pens comprising a strawed lying area (3.0 m $\times$ 2.2 m), a dunging area (2.0 m $\times$ 2.2 m) and five individual feeding stalls, into which the sows were shut over feeding. Water was available ad libitum from two nipple drinkers situated in each pen.
3. Large group ($n = 7$ from a single group of 37 sows). A large pen (16.5 m $\times$ 5.5 m) divided into a strawed lying area and a dunging area (5.1 m $\times$ 5.5 m). Part of the dunging area was occupied by an electronic sow feeder (ESF) unit in which the sows were fed one at a time (crate manufactured by Quality Equipment, Bury St. Edmunds, UK and electronics by Nedap Poiesz, Hengelo, Netherlands). Water was available ad libitum from nipple drinkers and a water trough situated in the dunging area.

Sows in the stalls and small groups were fed once a day at 07:30 h. For sows in the stalls, the stockman pulled a lever which delivered the feed to all sows simultaneously. For the sows in the small groups, the stockman delivered feed manually to each sow, one after another. In the large group, the computer-controlled feeding cycle started daily at 15:00 h and, although the sows could access the feeder as often as they wanted, the full day's allocation was invariably eaten during the first visit. All experimental sows were fed 2.2 kg day^{-1} throughout the period of the experiment. Each room was ventilated by thermostatically controlled 900 rev. min^{-1} 45-cm fans (one fan in each of the stall and small group systems and two fans in the ESF system), and supplementary heating was provided during cold weather. All rooms were lit by both natural daylight and artificial lighting with lights switched on at 06:00 h and off at 22:00 h. Thus, sows in all three rooms were exposed to similar ambient temperatures and photoperiods at all times. All dunging areas were cleaned daily and fresh straw was also added daily to the lying areas of the group-housing systems.

2.2. Heart rate monitoring

The heart rate monitor used in this study was the Polar Sport Tester (PST; Polar Electro Oy, Finland) consisting of an electrode belt, a clip-on transmitter and a wrist-watch receiver. The receiver has a memory function and stores data from the transmitter, averaging heart rate over 5-s, 15-s or 60-s intervals. In this study, the interval was set at 5 s for maximum detail, which gave a total memory capacity of 2 h 40 min.

The PST works by averaging the R–R intervals of the QRS electrocardiogram wave complex. After fitting, the first heart rate reading is calculated from the first four pulse values. Subsequent values are then calculated using a moving average over 5-s periods, as detailed by Karvonen et al. (1984). The system has been validated on humans (Karvonen et al., 1984, Seaward et al., 1990), horses (Sloet van Oldruitenborgh-Oosterbaan et al., 1988), cattle (Hopster and Blokhuis, 1994) and pigs (Baynes, P.J., personal communication, 1996) and provides valid recordings of heart-rate, even during high-intensity exercise when electrical artefacts from muscle contraction may be expected. The PST error-detection algorithm rejects artefacts which cause sudden heart rate changes of more than 40 b.p.m. and where this occurs, the last correct heart rate value is maintained until the receiver again obtains rational data from the transmitter. This generates straight lines on the graph, which are easily recognisable and are omitted from the analysis.

The electrode belt was fitted around the thorax of the sow without modification. ECG Gel (Camcare—Cambmac Instruments Ltd, Cambridge, UK) was applied to the electrode surfaces and, after ensuring that the skin surface was clean and dry, the electrode belt, plus transmitter, was placed around the thorax of the sow caudal to the forelimbs. One electrode was positioned in the ventral midline whist the other was located on the left side of the thorax in line with the olecranon process of the forelimb. The signal was tested using the receiver, and where necessary, the belt was adjusted about 10 cm ventrally or dorsally until the signal was consistent. The receiver was then fastened around the belt, positioned on the dorsal midline and activated to start recording.

After completion of data collection, the equipment was removed and the receiver downloaded by 'wire-free' contact via a Polar Interface (Polar Electro Oy, Finland) onto an Apple Macintosh computer. The data were displayed in graphical and numerical form using Polar Heart Rate Analysis Software Version 3.00 (Polar Electro Oy, Finland) and analysed.

2.3. Experimental protocol

All sows were weighed at the start of the experiment and parity and stage of gestation were recorded. Of the sows selected for the study, three were randomly chosen each day from each housing system and fitted with heart rate monitors. This procedure continued until all 21 sows had been recorded four times. The monitors were fitted to the sows in the small groups and stall systems at 07:00 h, 30 min before they were fed as part of the usual daily routine by the same stockman, and removed at 09:30 h. In the large group, the monitors were fitted to the sows at 14:30 h, 30 min before the computer feed cycle started, and removed at 17:00 h. Behaviour was recorded throughout this period by continuous direct observation from an elevated platform, so as not to disturb the sows. The specific behaviours which were recorded were feeding, drinking, rooting and lying with eyes open, as these were performed regularly by all sows in all three systems.

Heart rates and behaviour were also monitored between 12 and 15 h after feeding, the period during which the sows were most inactive. Basal heart rate was calculated from these periods, when the sow was lying laterally with eyes closed over an extended period of time.

2.4. Statistical analysis

The graphical and corresponding numerical data from the heart rate monitors were compared with the behavioural data, and marked to indicate when the specified behaviours occurred. The heart rate for each of the measured behaviours, except feeding, was averaged from 30 s after the start of that behaviour, in order to remove any effect on heart rate of previous behaviour, for a period of 5 min or until the behaviour ceased, whichever was the shorter. The heart rates for each behaviour were then averaged over the four recording sessions for each sow. These data were then analysed and heart rate during different behaviours was compared, first within each system and then between systems.

The time spent feeding was expected to range between about 10 and 15 min and therefore, four heart rate values were determined for each sow. These were: (1) a peak value—the mean of the highest heart rate values recorded during feeding in each of the four recording sessions; (2) 0–5 min mean value—the mean of all heart rate values recorded over the first 5 min of feeding in each of the four recording sessions; (3) 6–10 min mean value—the mean of all heart rate values recorded over the second 5 min of feeding in each of the four recording sessions; (4) 11–15 min mean value—the mean of all heart rate values recorded over the third 5 min of feeding in each of the four recorded sessions.

Heart rate over feeding was regressed against time over each of the 5-min periods, to determine the slope of the line of regression and the residual mean square. These were then compared within and between systems to give an indication of the magnitude and direction of heart rate change over time and the degree of heart rate variability.

All statistical analyses were performed using StatView SE + Graphics package (Abacus Concepts, California, USA). Within system comparisons were carried out using Friedman two-way analysis of variance (ANOVA). Between system comparisons were carried out using one-way ANOVA. However, variance was shown to differ significantly between treatments and hence, data were transformed by taking natural logarithms as appropriate when the assumption of normality was not fulfilled (Sokal and Rohlf, 1981).

3. Results

The type of behaviour being carried out had a significant effect on the heart rate of sows within each system (see Table 1). For all three systems, heart rate was highest during feeding and lowest during lying, with rooting and drinking intermediate. When comparing between systems (see Table 1), stall-housed sows had significantly higher basal heart rates and heart rates during feeding than group-housed sows from either system ($P < 0.05$). In addition, stall-housed sows had significantly higher heart rates whilst rooting, drinking and lying with their eyes open than sows from the ESF house ($P < 0.05$). There were no significant differences in mean peak values at feeding between the three systems (stalls, 149.1 b.p.m.; small group, 154.8 b.p.m.; large group, 135.5 b.p.m.; $F = 2.21$, d.f. = 2,18, $P = 0.139$).

The higher heart rates of the stall-housed sows during the specified behaviours could have been a consequence of the significant differences in basal heart rates, so increases in heart rate over basal levels were calculated (see Table 2). There were no significant differences between the three systems in the increases in heart rate over basal levels for the behaviours of rooting, drinking and lying with eyes closed. However, the increases in average heart rate during feeding were significantly different, with stall-housed sows higher than both sets of group-housed sows. In addition, the mean peak feeding heart

Table 1
Mean (95% confidence limits) heart rate response in beats per minute during specified behaviours, compared within and between systems

Behaviour	Treatment			F-value (d.f. = 2,18)	ANOVA P-value
	Stalls ($n = 7$)	Large group ($n = 7$)	Small group ($n = 7$)		
Basal	53.8a (48.8–59.4)	46.5b (41.8–51.7)	45.8b (42.4–49.4)	5.42	0.014
Feeding (0–5 min)	118.0a (108.0–128.9)	105.5b (98.1–113.6)	102.4b (98.7–106.3)	6.84	0.006
Rooting	92.4a (85.8–99.5)	82.3b (75.7–89.7)	87.4ab (81.6–93.8)	3.55	0.052
Drinking	99.5a (95.7–103.4)	89.7b (83.1–97.0)	96.5ab (88.8–105.1)	3.45	0.054
Lying	66.1a (61.4–71.2)	55.8b (52.4–59.4)	57.2b (47.7–68.7)	4.49	0.027
χr^2	27.31[a]	28.00[a]	22.93[a]		

[a] $P < 0.001$—Friedman two-way analysis of variance within systems.
Data were transformed by taking natural logarithms. Reported means and 95% confidence limits are back-transformed.
Means on a row followed by different letters are significantly different ($P < 0.05$) using the Fisher PLSD post hoc test.

rate of sows housed in small groups was significantly higher than the mean peak feeding heart rate of sows housed in the large group (see Table 2).

At first inspection, the profiles of heart rate over time during feeding for all three systems appeared to be similar (see Fig. 1), showing an immediate rise at feed delivery,

Table 2
Mean (95% confidence limits) change in heart rate in beats per minute from basal levels during specified behaviours, compared between systems

Behaviour	Treatment			F-value (d.f. = 2,18)	ANOVA P-value
	Stalls ($n = 7$)	Large group ($n = 7$)	Small group ($n = 7$)		
Feeding (0–5 min avg.)	+64.2a (57.9–70.7)	+59.0b (55.8–62.6)	+56.4b (53.6–59.5)	4.53	0.026
Feeding (0–5 min peak)	+93.2ab (77.0–112.8)	+88.4a (81.0–96.5)	+107.8b (93.1–124.6)	2.87	0.083
Rooting	+37.2 (28.3–48.9)	+35.0 (27.9–44.0)	+41.6 (36.3–47.6)	0.84	0.450
Drinking	+44.9 (38.1–52.9)	+42.7 (35.6–51.0)	+50.3 (42.6–59.5)	1.49	0.252
Lie (eyes open)	+9.5 (4.5--20.3)	+6.8 (2.8–16.6)	+10.2 (5.3–19.8)	0.46	0.636

Data were transformed by taking natural logarithms. Reported means and 95% confidence limits are back-transformed.
Means on a row followed by different letters are significantly different ($P < 0.05$) using the Fisher PLSD post hoc test.

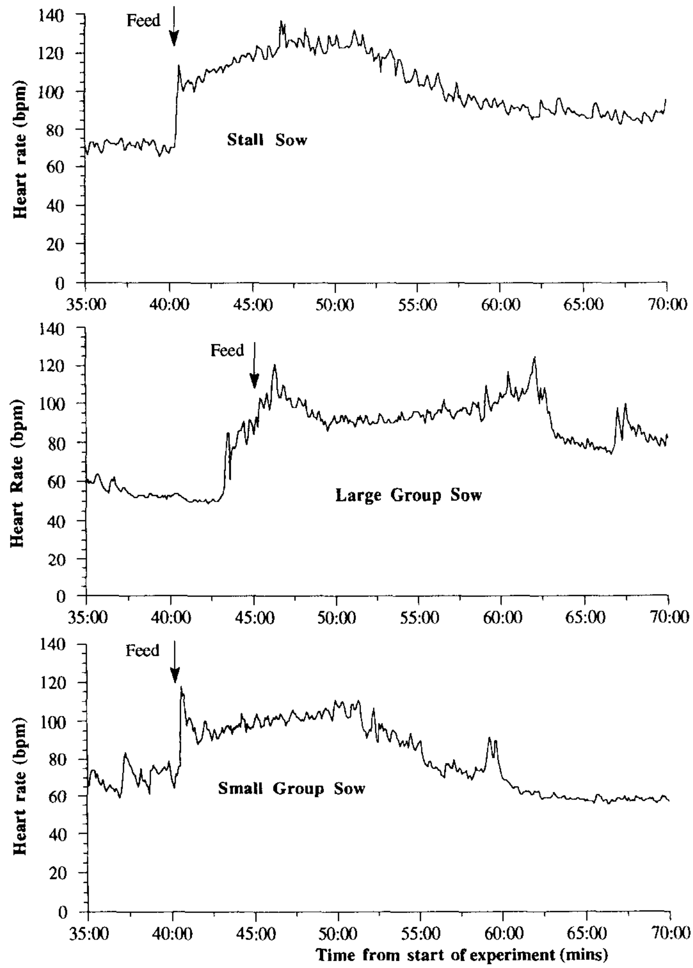

Fig. 1. Examples of profiles of heart rate response to feeding (b.p.m.) for individual sows from each dry sow system. Arrow denotes time of feed delivery.

a sustained elevated heart rate during feeding followed by a gradual decrease once the food had been eaten. Regression analysis, however, revealed that there were significant differences in magnitude and direction of heart rate change over the first two periods of feeding between sows housed in stalls and both sets of those housed in groups (see Table 3). Also, during the first 5 min of feeding, the heart rate of sows feeding in the ESF system was less variable than those feeding in proximity to other sows in the stalls and small group systems.

Table 3
Mean (95% confidence limits) heart rate response in beats per minute, regression slopes and regression residual mean squares during feeding, compared within and between systems

Parameter	Treatment			F-value (d.f. = 2,18)	ANOVA P-value
	Stalls (n = 7)	Large group (n = 7)	Small group (n = 7)		
Heart rate 0–5 min	118.0a (108.0–128.9)	105.5b (98.1–113.6)	102.4b (98.7–106.3)	6.84	0.006
Heart rate 6–10 min	124.0a (109.4–140.5)	108.4b (98.2–119.7)	106.4b (96.8–116.9)	3.66	0.046
Heart rate 11–15 min	120.7a (111.9–130.2)	109.0b (100.9–117.6)	108.0b (100.3–116.3)	4.03	0.036
χr^2	3.71	0.86	1.14		
Regression slope 0–5 min	+0.63a (+0.27 – +1.11)	−0.14b (−0.22 – −0.04)	−0.30b (−0.44 – −0.13)	19.99	0.001
Regression slope 6–10 min	−0.35a (−0.60 – +0.07)	+0.01b (−0.04 – +0.07)	+0.10b (−0.04 – +0.26)	5.41	0.014
Regression slope 11–15 min	+0.06 (−0.05 – +0.18)	−0.02 (−0.25 – +0.28)	−0.28 (−0.66 – +0.51)	1.15	0.339
χr^2	12.28[a]	3.71	6.74[a]		
Residual mean square 0–5 min	56.7a (22.0–146.4)	14.6b (8.4–25.4)	44.6a (29.6–67.1)	4.39	0.028
Residual mean square 6–10 min	33.4a (13.6–81.9)	13.8b (8.2–23.4)	12.8b (5.2–31.6)	3.57	0.049
Residual mean square 11–15 min	60.6 (22.1–166.5)	42.7 (18.5–98.5)	40.3 (18.3–88.8)	0.47	0.632
χr^2	4.57	10.57[a]	10.57[a]		

[a] $P < 0.05$—Friedman two-way analysis of variance within systems.
Data were transformed by taking natural logarithms. Reported means and 95% confidence limits are back-transformed.
Means on a row followed by different letters are significantly different ($P < 0.05$) using the Fisher PLSD post hoc test.

4. Discussion

The heart rates of stall-housed sows were higher than those of the group-housed sows during feeding, rooting, drinking and lying with eyes open. These results would seem to indicate an increased sympathetic nervous response to all these behaviours, but the basal heart rate levels were also higher in stall-housed sows than in group-housed sows. The increases in heart rate over basal heart rate were not significantly greater for drinking, rooting and lying with eyes open in stall-housed sows. The elevated basal levels experienced by the stall-housed sows are therefore probably the single most important factor contributing to the higher heart rates during drinking, rooting and lying with eyes open. The fact that stall-housed sows had significantly higher basal heart rates may be indicative of them having reduced cardiovascular fitness, due to an inability to exercise. Although other factors such as age, weight and stage of gestation (Marchant and Broom, 1995) may affect basal heart rate, in this study there were no significant differences in these factors between the three housing systems.

Like all muscle, the heart requires regular exercise to maintain efficiency, i.e. activity which results in positive chronotropic and inotropic changes for an extended period. Activity which does not result in these cardiac changes will not influence cardiac efficiency. Although stall-housed sows may show either a decrease in overall activity compared with group-housed sows (Gravås, 1982, Carter and English, 1983, Broom et al., 1995), or an increase (Bengtsson et al., 1983, Cariolet and Dantzer, 1985), the spatial restriction imposed by confinement means that the opportunity to exercise is all but impossible. The long-term effects of this lack of exercise are uncertain because of the artificially shortened lifespan of sows in commercial farming practice, yet it is known that stall-housed sows do suffer a greater incidence of cardiovascular disease (Ratcliffe et al., 1969). Although Schouten et al. (1991) did not detect any change in resting heart rates between loose-housed or tethered sows, this may have been due to the short-term tethering periods carried out in their study (maximum 6–8 months). The sows used in our study had been kept in stalls over a period of 36–42 months, except during the farrowing periods.

Variation in housing temperature could affect basal heart rates. In this study, ambient house temperature was kept consistent in the three systems by use of thermostatically controlled ventilation and supplementary heating when necessary and thus, air temperature could not have had a major effect on metabolism. However, both group-housed systems are straw-based, whereas the stall-house system has an insulated concrete floor. Potentially, over the long term, this represents a greater conductive heat-loss for sows housed on concrete, since none of the whole-house temperatures were maintained at an optimum 21–22°C. This loss may be compounded by an inability to thermoregulate by muscular exercise. Therefore, physiological compensation may be achieved through an increase in metabolic rate with a corresponding increase in basal heart rate.

With the basal levels taken into account, the finding that the response of stall-housed sows to feeding was significantly higher than that of group-housed sows, indicates the importance of the feeding event in the stall sows' day. Stall-housed sows are less responsive than group-housed sows to various stimuli other than feeding (Broom, 1986a,b, 1987). Schouten et al. (1991) have demonstrated that the difference between confined and loose-housed sows in heart rate response to feeding is partly blocked by a beta-adrenergic receptor blocker, and not by naloxone, indicating it may be due to an increased sympathetic nervous response in confined sows, which is not reduced by endogenous opioids.

The differences in the peak feeding values, the slopes of the lines of regression and the residual mean squares may be explained largely in terms of the physical activity associated with locomotion and the psychological state associated with the instancy of feed delivery and agonistic interactions. Increased sympathetic tone is normally associated with reduced heart rate variability (Bigger et al., 1988), where variability is measured in terms of individual R–R intervals. By using a moving average over 5 s, the PST is not capable of elucidating beat-to-beat changes and thus, the variability of heart rate illustrated by the residual mean square pertains to longer term fluctuations most likely associated with bursts of sympathetic-adrenal medullary activity in response to psychologically disturbing events. Agonistic interactions have been shown to greatly increase heart rate in both the initiator and the receiver even when there is no physical contact (Marchant et al., 1995).

During the first 5-min period, heart rate is still being influenced by previous activity and the amount of social interactions before feeding and the anticipation of feed delivery itself. For the sows housed in the small groups, feed was delivered manually to each sow in turn and thus, at the instant of feed delivery for any one individual, one neighbouring sow would already have feed while the other neighbouring sow would be without. The degree of anticipation and intensity of social interaction with neighbours was probably high at this time which, in addition to the residual effects of locomotor activity prior to entry into the feeding stalls, resulted in a significantly higher peak heart rate immediately after feed delivery. Thereafter, the heart rate gradually decreased, as indicated by the slope of the line of regression, although variability over the first 5-min period remained significantly high.

For the sows housed in the stalls, there was little anticipation as feed delivery was instantaneous and simultaneous. This, together with the very limited opportunity for locomotion resulted in relatively low heart rates at the start of feeding but a rapid and high sympathetic nervous response, indicated by the positive slope of the line of regression, over the first 5-min period. The variability of the heart rate was also high over this period.

Sows housed in the large group could engage in locomotion and social interactions prior to feeding but, once in the feeder station, were able to eat their ration in an enclosed environment free from any visual and tactile contact with other sows. Feed was delivered quickly after entry to the feeder, so again, any effect of anticipation was slight. The combination of these factors resulted in the lowest peak heart rate over the first 5-min period, a gradual decrease in heart rate over time and a significantly low variability in heart rate.

Over the second 5-min period, all sows were eating continually. For both sets of group-housed sows, this stability of behaviour is indicated by significantly low heart rate variability and relatively flat lines of regression. The stall-housed sows show a decreasing sympathetic nervous tone but continue to show a high variability, probably indicative of adrenal responses to continued aggression.

At some point during the third 5-min period, all the sows finished their ration. The sows in the small groups and the stalls had received all their ration in one delivery and thus, once finished, would know that there was no more to come. However, sows would be finishing at different times and, once finished, would direct behaviour at any neighbouring sow which was still eating. Thus, variability was relatively high compared with the previous 5-min period. The sows in the ESF system received feed in pulsed deliveries and therefore, even after the last allocated feed had been dispensed, would probably still be expecting more. Heart rate variability also increased over this last period for these sows possibly due to frustration of these expectations. The slope of the line of regression was negative for the small group sows due to some individuals choosing to lie down in the stalls after feeding.

These results highlight the importance of providing a feeding system which allows the sow to obtain her nutritional requirements without competition. Floor feeding systems have been shown to give rise to very high levels of aggression with low ranking animals being particularly disadvantaged and deprived of sufficient feed (Edwards et al., 1993). Although individual feeding stalls do ensure that all sows receive adequate feed, there is still an element of psychological threat which may make feeding a stressful event, especially for subordinate sows housed next to more dominant animals, and especially where there is great variation in eating speeds. It has been shown that the variation in eating speed can be reduced by adding water (Bøe, 1996) and thus, wet feeding systems may reduce stress at feeding.

In summary, heart rate in sows varies with respect to behaviour, being lowest when lying sleeping and highest when feeding, which elicits an increase in heart rate above that seen during behaviours involving similar physical components (rooting and drinking). Long-term confinement in stalls results in an increased basal heart rate and an increased physiological response to feeding, probably due to an increased sympathetic nervous response. This illustrates the importance of the feeding event to sows housed in this system. Feeding environments which allow contact between sows result in higher peak feeding heart rates and greater heart rate variability, probably due to short-term adrenal responses to agonistic interactions.

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