Effects of thermal environment on hypothalamic-pituitary-adrenal axis hormones, oxytocin, and behavioral activity in periparturient sows


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ABSTRACT: Provision of additional floor heating (33 to 34°C) at birth and during the early postnatal hours is favorable for newborn piglets of domestic sows (Sus scrofa). We investigated whether this relatively high temperature influenced sow behavior and physiology around farrowing. One-half of 28 second-parity pregnant sows were randomly chosen to be exposed to floor heating 12 h after onset of nest building and until 48 h after birth of the first piglet (heat treatment), whereas the rest of the sows entered the control group (control treatment) with no floor heating. Hourly blood sampling from 8 h before and until 24 h after the birth of the first piglet was used for investigation of temporal changes in plasma concentrations of oxytocin, cortisol, and ACTH. In addition, occurrence and duration of sow postures were recorded −8 to +48 h relative to the birth of the first piglet. There was a clear temporal development in sow behavior and hormone concentrations (ACTH, cortisol, and oxytocin) across parturition (P < 0.001), independent of treatment. In general, hormone concentrations increased from the start to the end of farrowing. The observed oxytocin increase and peak late in farrowing coincided with the passive phase where sows lie laterally with an overall reduced activity. Floor heating increased the mean concentration of cortisol (P = 0.02; estimated as 29% greater than in controls) and tended to increase the mean concentration of ACTH (P = 0.08; estimated as 17% greater than in controls), but we did not find any treatment effect on mean oxytocin concentrations, the course of parturition, or the behavior of sows. Behavioral thermoregulation may, however, have lost some function for the sows because the floor was fully heated in our study. In addition, exposure to heat decreased the between-sow variation of plasma oxytocin (approximately 31% less relative to control) and ACTH (approximately 46% less relative to control). Whether this decreased variation may be indicative of acute stress or linked to other biological events is unclear. In conclusion, inescapable floor heating (around 33.5°C) may be considered a stressor for sows around farrowing, giving rise to elevated plasma concentrations of cortisol, but without concurrent changes in oxytocin or behavioral activity.

Key words: behavior, hypothalamic-pituitary-adrenal axis, oxytocin, parturition, Sus scrofa

INTRODUCTION

A warm environment is regarded as a stressor for lactating sows, reducing their feed intake and milk production as the lactation period proceeds (e.g., Biensen et al., 1996). Consequently, ambient temperatures in the range of 18 to 23°C are recommended as optimal in maintaining sows during pregnancy and the period of lactation. However, the heat requirement of the newborn piglets is greater, and a considerable thermoregulatory challenge typically faces piglets at delivery (Herpin et al., 2002). Provision of additional floor heating (33.5°C) on-site at the time of birth and during the early postnatal hours has been proven favorable for the initiation of suckling and for the survival of piglets (Malmkvist et al., 2006). It is, however, unknown whether this piglet-friendly thermal environment affects the sow during the different phases of parturition, in such a way that floor heating should be recognized as a stressor of periparturient sows. Stress may negatively interfere with the progress of parturition and periparturient behavior. This has been reported or at least hypothesized for several species of mammals (e.g., Leng et al., 1987; Biensen et al., 1996). The objective of the present study
was to investigate the effect of a piglet-friendly thermal birth environment on physiology and behavior of sows around farrowing. In particular, we investigated the effects of an increased floor temperature on the temporal changes in ACTH, cortisol, oxytocin, and behavioral activity in sows across parturition.

**MATERIALS AND METHODS**

All procedures involving animals were approved by the Danish Animal Experiments Inspectorate in accordance with the Danish Ministry of Justice Law No. 382 (June 10, 1987) and Acts 333 (May 19, 1990), 726 (September 9, 1993), and 1016 (December 12, 2001).

**Animals, Housing, and Care**

We used 28 pregnant Danish Landrace × Yorkshire sows of second parity from 1 wk before expected farrowing (i.e., d 108 to 109 of gestation) until 48 h after farrowing. The sows were housed individually in 7.5-m² pens in a climate-controlled facility (Figure 1). A water-based heating system was built into the concrete floor of the pen, and in addition piglets were given access to an area with a heat mat (model ESS-004, 2000W, from Rexlan Europe, Soroe, Denmark). The sows were introduced to the farrowing pens 7 d before expected farrowing to accustom them to the experimental pen. Before this, the sows were loose-housed in groups, and all sows had been loose-housed during their previous farrowing. The sows were fed twice daily with a standard dry sow diet (16.6% CP, 8.4 MJ of NE/kg) for lactating sows.

The daily ration was 2.6 kg during the experimental period. The sows had free access to drinking water and barley straw for nest building. The water consumption period was evaluated twice per day at 0800 and 2000 h beginning on d 112 of gestation using digital video surveillance recordings. The onset of nest building was defined as the first occurrence of at least 5 front leg pawings/h or repeated carrying of straw, without being interrupted by resting periods longer than 2 h [modified from Thodberg et al. (2002) and Pedersen et al. (2003)]. As a consequence of the individual variation in the duration from start of nest building until the beginning of farrowing, the HT-sows were exposed to floor heating for a variable amount of time, on average (±SE) 12 h 35 min (±1 h 59 min), before the birth of the first piglet.

The criteria for sows to enter the experiment were a minimum delivery of 8 liveborn piglets and a good health condition (i.e., sows receiving medical treatment 1 wk before and during farrowing were excluded). Hence, the results are based on sows needing neither human nor pharmaceutical aid during farrowing. Eight out of the original 28 sows were excluded due to medical treatment/farrowing assistance (2 CONT, 1 HT sow), too few liveborn piglets (1 CONT sow), floor heating being activated too late before farrowing (1 HT sow), or catheter clotting/failure (1 CONT, 2 HT sows), reducing the number of experimental sows to 20 (10 CONT, 10 HT). The BW of the 20 sows, measured at 110 to 111 d of gestation, did not differ (P = 0.7) between treatments: CONT: 246 kg (±5.2 kg) vs. HT: 243 kg (±5.0 kg).

**Other Handling**

We removed piglets from litters with more than 14 live piglets (the number corresponding to the number of teats) 25 h after birth of the first piglet. The surplus piglets were chosen randomly and removed to foster sows outside the experimental room. The experiment presented here was part of a larger project. Data on early piglet vitality and behavior related to survival are reported in Malmkvist et al. (2006). The sow responsiveness, observed as posture changes, during the regular piglet handling and sampling was low; on average only 5% responded to this during all times from birth of first piglet (BFP) until 24 h after birth of first piglet (reported in Chaloupková et al., 2008).

**Behavior**

A digital video camera was placed above each pen, and all cameras were connected to a computer that stored the video files (using MSH-Video software, M. Shafro & Co., Riga, Latvia). The occurrence and duration of sow postures (lying laterally, lying in sternal position, sitting, and standing/walking) were observed continuously from the stored recordings. The frequency of postural changes and the duration per hour of lying laterally and standing/walking were calculated. The total observation period was divided into 4 periods relative to the BFP, and the hourly frequency/duration was calculated within each period. Period 1 included...
hours during nest building (−8 to −2 h before BFP), period 2 was the last 2 h before farrowing (−2 to 0 h before BFP), period 3 included hours during farrowing (0 to +8 h after BFP), and period 4 was after farrowing (+8 to +48 h after BFP). These periods were chosen due to different expectations of the level of activity, as
Catheterization, Blood Sampling, and Analyses of Blood

On gestation d 110 to 111, a jugular catheter was inserted in all sows by a nonsurgical venipuncture without use of anesthesia using the method described in Damm et al. (2000). From the day after catheterization, daily blood samples (2 to 4 mL) were taken before morning feeding around 0800 h to maintain the flow. In addition, from 12 h after the onset of nest building until 24 h after BFP, hourly blood samples were taken. The total number of hourly blood samples taken varied (minimum: 23, maximum: 38) because of the variation in duration from the onset of nest building until delivery. Blood sampled earlier than 8 h before the BFP were not analyzed.

Blood was collected in plastic tubes with added K-EDTA plastic tubes (4-mL vacuette from Greiner Bio-One, Austria), stored ice-cold, and centrifuged within 1 h at 2,000 × g for 20 min at 4°C. The plasma was separated and stored at −20°C until analysis. Oxytocin concentration in plasma was determined using the extraction and RIA method with the minimum detection limit of 0.25 ng/L, the intraassay CV below 7.9% for 2 control samples, and the interassay CV varied between 10.8 and 17.3% for 5 control samples with low and high concentrations as described in Schams (1983). The plasma concentration of cortisol was determined by solid-phase RIA (Diagnostic Products Corporation, Los Angeles, CA) according to the manufacturer’s instructions. The minimum amount of cortisol detectable was 5.5 nmol/L, equivalent to 2.0 ng/mL (because 1 nmol/L = 0.362 ng/mL). Intraassay CV were 7.1, 5.6, and 4.6%, and the interassay CV 11.3, 10.7, and 12.7% at 71.0, 160.0, and 333.6 nmol/L, respectively. The plasma concentration of ACTH was determined by RIA (Diagnostic Systems Laboratories, Webster, TX). The sensitivity of the analysis was 3.5 ng/L. The intraassay CV were estimated as 11.4 and 16.6%, and the interassay CV were 26.1 and 22.9% at 39.1 and 309.6 ng/L, respectively.

Statistics

The frequency per hour of postural changes and the time spent standing/walking and time spent lying laterally were analyzed using a linear normal mixed model including treatment (CONT, HT) and periods as well as the interaction between them as fixed effect and sows as random effect. The covariance structure between repeated measures was modeled with compound symmetry. The calculations were made using the mixed procedure (SAS Inst. Inc., Cary, NC; Littell et al., 1996), and Satterthwaite’s approximation was used for calculation of degrees of freedom.

The data for blood hormones were also analyzed using linear normal mixed models. The analyses were performed using R (R Development Core Team, 2005) and the packages nlme (Pinheiro et al., 2005) and splines (Hastie, 1993). The basic model was formulated as follows:

\[ Y_{ijk} = \mu + S_{ij} + \alpha_i + f(t_{ijk}) + \varepsilon_{ijk}, \]

where \( Y_{ijk} \) is the logarithmic transformed value of hormone concentration (oxytocin, ACTH, and cortisol) for sow \( j \) on treatment \( i \) at observation \( k \). The general intercept is termed \( \mu \), \( S_{ij} \) is the random effect of sow \( S_j \sim N(0,\sigma^2_{S}) \), and \( \alpha_i \) is the effect of heat treatment \( i \). The \( f \) is a function describing the difference from the mean level at the time \( t_{ijk} \) of the observation, described in detail below. The residual was assumed normally distributed with treatment specific variance, \( \varepsilon_{ijk} \sim N(0,\sigma^2_{\varepsilon}) \).

An autocorrelated variance structure of the repeated measurements was assumed, the correlation between measurement \( k \) and \( k' \) for sow \( j \) within treatment \( i \) was \( \rho_{kk'} = \rho^{k-k'} \). This simple autocorrelation structure was extended to produce a more flexible model of the variability at the sow level. Random regressions model for the time development of the sow was investigated (i.e., addition of terms like \( B_{iij} t_{ijk} + B_{2ij} t_{ijk}^2 + \ldots \) with \( B_{iij} \) corresponding to random sow-specific regression coefficients). The maximal model tested was a quadratic polynomial. However, due to numerical problems in the estimation procedure, these models did not always converge. The degree of the polynomial in the random regression was subsequently reduced to minimize Akaike’s information criteria (AIC; Akaike, 1974; Burnham and Anderson, 2002). The degrees of the polynomials in final model were oxytocin 0 (2), ACTH 0 (0), and cortisol 1 (1), where the number in parentheses indicates the maximal degree.

Initially, it was unknown whether taking the duration of parturition into account would improve the models of hormonal changes around farrowing. Therefore, 2 time-scales were compared, called chronological and standardized. In both cases the time-scale was centered, so that start of farrowing (i.e., BFP) was set to zero. The chronological time-scale \( t^c_{ijk} \) equals \( (t_{ijk} - t_{s,ij}) \), where \( t_{ijk} \) is the chronological (real) time at the observation and \( t_{s,ij} \) is the time at the start of farrowing (i.e., BFP). The standardized time-scale took the duration of parturition into account. The end of parturition \( t_{e,ij} \) was defined as the birth of the last piglet. The average duration of the parturition \( (t_{e,ij} - t_{s,ij}) \) was approximately 4 h. This was used in the standardized time-scale \( t^*_{ijk} \), defined as follows:

\[ t^*_{ijk} = t^c_{ijk} \text{ for } r_{ijk} < t_{s,ij}, \]
\[ t^*_{ijk} = 4 \left( t_{ijk} - t_{s,ij} \right) \left( t_{e,ij} - t_{s,ij} \right) / \left( t_{e,ij} - t_{s,ij} \right) \text{ for } t_{s,ij} \leq r_{ijk} \leq t_{e,ij} \]
\[ t^*_{ijk} = 4 + \left( r_{ijk} - t_{e,ij} \right) \text{ for } r_{ijk} > t_{e,ij}. \]
The 2 models (with different time-scales) do not differ in number of variables (i.e., a formal significance test via likelihood ratio test is not valid). Instead AIC (Akaike, 1974) was used. The functional form of the fi was defined as a natural spline function (e.g., Hastie, 1993) with 3 df with boundary knots at time −9 and 10, breakpoints at time (−1, 4) defined via the standard approach of the ns function in R.

A probability level of 0.05 was chosen as the limit of statistical significance in all tests concerning the main experimental hypothesis. The P-values between 0.05 to 0.10 are reported as tendencies. As mentioned, AIC was used for choosing the variance structure as well as the time-scale. Based on the models, BLUP were calculated for the predicted level of each sow at each observation.

**RESULTS**

**Behavior**

There were no effect of treatment on the number of postural changes ($F_{1,18} = 0.5, P = 0.5$), on the time spent in lying laterally ($F_{1,18} = 0.1, P = 0.7$) and on time spent standing/walking ($F_{1,18} = 2.2, P = 0.16$). Period affected the number of postural changes ($F_{3,57} = 64.6, P < 0.001$) (in number per h; period 1: 9.0 ± 0.71; period 2: 9.4 ± 0.71; period 3: 2.4 ± 0.71; period 4: 2.5 ± 0.71), time spent in lateral recumbency ($F_{3,57} = 43.5, P < 0.001$; in min per h; period 1: 13.0 ± 2.5; period 2: 35.2 ± 2.5; period 3: 55.6 ± 2.5; period 4: 45.5 ± 2.5) and time spent standing/walking ($F_{3,57} = 70.7, P < 0.001$; in min/h; period 1: 33.7 ± 1.9; period 2: 10.5 ± 1.9; period 3: 1.5 ± 1.9; period 4: 6.3 ± 1.9). There was no interaction between treatment and period for any of the variables (Table 1).

**Blood Hormones**

The concentrations of hormones in blood varied significantly with time ($P < 0.05$) during the periparturient period included in the analysis (−8 to +8 h relative to BFP). For all 3 hormones, the time-scale that took the duration of parturition into account separately (the standardized time-scale) gave the best fit to the data with differences in AIC ranging from 7 to 33. The residual SD differed between treatments for oxytocin and ACTH. In general, the hormonal concentration increased from start to the end of farrowing. The results are described in detail below.

**Oxytocin.** The final model (i.e., with the least AIC) was based on the standardized time-scale with treatment dependent variance, including random effect of sow and an autoregressive model for residual correlation, but without the random regression part. There was no interaction between time and treatments ($F_{3,243} = 0.6, P = 0.6$) and no effect of treatment ($α_i; F_{1,18} = 0.3, P = 0.6$). The residual SD was different in the 2 treatments. The estimated residual SD was without

| Table 1. Time spent in different postures and number of postural changes given as least squares means ± SE during 4 periods around farrowing.1 |
|----------------|----------------|----------------|----------------|----------------|
|                | CONT sows      | HT sows        | P12            | P23            |
| Lat. lying, min/h | 13.1 ± 3.50a | 33.7 ± 3.50c | 12.8 ± 3.50c | 12.8 ± 3.50c  |
| Sternal lying, min/h | 7.6 ± 1.72a | 7.7 ± 1.72a | 5.6 ± 1.72a | 4.8 ± 1.72a  |
| Stand./walk, min/h   | 35.8 ± 2.58a | 15.0 ± 2.58b | 6.4 ± 2.58b | 6.4 ± 2.58b  |
| Postural changes, number/h | 9.6 ± 1.0a | 10.2 ± 1.0a | 2.3 ± 1.0b | 2.4 ± 1.0b  |

1Different letters within rows indicate significant differences between periods, $P < 0.05$. There was no difference between CONT and HT sows and no interaction between treatment and period.2CONT = no floor heating; HT = exposed to floor heating.3P1 = period 1: −8 to −2 h before birth of first piglet.4P2 = period 2: −2 to 0 h before birth of first piglet.5P3 = period 3: 0 to +8 h after birth of first piglet.6P4 = period 4: +8 to +48 h after birth of first piglet.
heat $\sigma_{E,1} = 1.25$ and with heat $\sigma_{E,2} = 0.86$ (i.e., the SD was approximately 31% less for the HT treatment). The estimated curves for the 2 treatments are shown in Figure 2. The effect of time was highly significant ($F_{3,245} = 21.9, P < 0.001$).

**ACTH.** The final model included treatment-specific variance and an autoregressive variance structure. There was no interaction between time and treatment ($F_{3,243} = 0.5, P = 0.7$), but there was a difference in residual SD and a tendency to an overall difference between treatments ($F_{1,18} = 3.5, P = 0.08$). The estimated residual SD were for the CONT treatment $\sigma_{E,1} = 0.28$ and for the HT treatment $\sigma_{E,2} = 0.15$; thus the SD was 46% less for the HT treatment. The effect of heat was estimated to be $0.17 \pm 0.09$ on the log scale or approximately 17% increase in the average plasma ACTH concentration relative to the control group (Figure 3). Due to numerical difficulties, the random regression model could not converge and was therefore not tested for ACTH.

**Cortisol.** The final model contained only the linear random regression model with autoregressive variance structure and was based on variance homogeneity. Variance homogeneity resulted in a slightly better fit based on AIC. There was no interaction between time and treatment ($F_{3,247} = 1.9, P = 0.12$). There was an effect of the heat treatment ($F_{1,18} = 6.1, P = 0.02$). The effect of heat was estimated to be $0.29 \pm 0.11$ on the log scale or approximately 29% increase in cortisol concentration relative to the CONT treatment (Figure 4).

**DISCUSSION**

The floor heating (33.5°C) elevated the overall plasma concentration of anterior pituitary-adrenocortical hormones (i.e., a tendency for greater concentration of ACTH and a significant greater concentration of cortisol) when sows were housed in an ambient temperature of 21°C. The relative high interassay CV of the ACTH assay may impair the chances of treatment effects reaching significance in our study. Endocrine stress responses have previously been reported for swine in high temperature treatments. There are several investigations showing increased cortisol after a shorter period of increased ambient temperatures (Larsson et al., 1983; Bate and Hacker, 1985; Hyun et al., 1998). Bate and Hacker (1985) found a disrupted circadian rhythm of cortisol concurrent with increased nighttime cortisol in 4 gilts subjected to 3 d of high ambient temperatures (32°C) compared with the preceding 3 d when the same gilts were subjected to 15°C. Also, Larsson et al. (1983) found increased cortisol in 4 boars moved from 20 to 35°C for 100 h compared with 4 control boars moved from 20 to 20°C. Marble et al. (1972) reported an increase in plasma ACTH (but not significant for corticoids) in 4 gilts exposed to a high temperature (32.2°C) environment after having been exposed to a 12-d period of 4.4°C and changing humidity. Other types of stressors have previously been shown to increase the concentration of ACTH and cortisol in pigs [e.g., nose snaring (Rushen et al., 1993), prepartum increases of plasma.
Figure 3. Estimated periparturient development in plasma ACTH concentration (ng/L) in the 2 treatment groups (tendency of treatment difference, $P = 0.08$) with 10 sows per treatment. Farrowing duration was standardized to 4 h. The y-axis is logarithmically scaled. Triangles/dashed line: heat treatment. Circles/solid line: control treatment. Points indicate BLUP values at each observation for each sow.

Figure 4. Estimated periparturient development in plasma cortisol concentration (nmol/L; 1 nmol/L is equal to 0.362 ng/mL) in the 2 treatment groups (additive effect of heat was significant, $P = 0.02$) with 10 sows per treatment. Farrowing duration standardized to 4 h. The y-axis is logarithmically scaled. Triangles/dashed line: heat treatment. Circles/solid line: control treatment. Points indicate BLUP values at each observation for each sow.
cortisol in sows induced by moving to crates without bedding (Lawrence et al., 1994), and by nest removal (Damgaard et al., 2003). In contrast to the relatively short duration of elevated temperatures used in our study (average 2.5 d), long-term exposure to elevated ambient temperatures (more than 3 wk at 30°C) has been found to reduce cortisol concentrations in sows (measured 4 and 19 d postpartum), which was suggested to be an endocrine adaptation to avoid hyperthermia during exposure to high ambient temperatures (de Braganca et al., 1998).

It should also be considered that, although stressors may change ACTH or cortisol concentrations, glucocorticoid hormones also play an important role in several basic physiological processes, such as energy metabolism (for a review see Mormede et al., 2007). In the present experiment, there may be influences on the hypothalamic-pituitary-adrenal (HPA) axis not only from the increased floor temperatures but also from metabolic and hormonal changes due to the birth process that also interacts with the activity in the HPA axis. Stressors leading to increased HPA-axis hormones (van de Kar and Blair, 1999; Matteri et al., 2000) may influence oxytocin release during parturition and prolong the parturition in polytocous species, such as rats (Rattus norvegicus) and pigs (Sus scrofa). For example, moving to a new environment during mid-parturition prolonged the birth process in rats (Leng et al., 1987, 1988). Similarly, moving of sows to a farrowing crate during mid-parturition resulted in depressed oxytocin release through opioid inhibition and a prolonged birth process (Lawrence et al., 1992). In our study, there was no evidence that the increased cortisol and ACTH inhibited plasma oxytocin in the sows. In addition, the birth process, measured as the duration of parturition and the variation in interbirth intervals between piglets reported in Malmkvist et al. (2006), did not differ between HT and CONT sows.

Chaloupková et al. (2008) reported posture changes in sows during hourly blood sampling, based on the same setup as in the present study. They reported a relatively low responsiveness of sows during the early postdelivery period (5% of sows reacted), compared with during parturition (11% reacted) and in the later period from 12 to 24 h after BFP (15% reacted). However, no control (e.g., observation of sows not sampled or of sows during periods without sampling) was included in this study. The results on sow responsiveness toward blood sampling may therefore also reflect the well-known changes in sow activity during and after parturition (e.g., Jarvis et al., 1999; Pedersen et al., 2003) rather than being induced by the blood sampling procedure. We used the same sampling procedures on all sows and therefore did not introduce any treatment bias. Additionally, the sows appeared habituated to the sampling procedures. In our experimental animals, the plasma cortisol concentration 5 d before parturition was 136 nmol/L (equivalent to 49 ng/mL). From d +2 to +6 after farrowing, the mean concentration was almost constant, around 100 to 125 nmol/L (equivalent to 36 to 45 ng/mL), with no interaction between heat treatment and day in relation to parturition (reported in Damgaard et al., 2009). The prefarrowing cortisol concentration in our control sows was close to the mean value 5 to 4 h before farrowing for crated sows (mean concentration of about 150 nmol/L) reported in Jarvis et al. (2001). They reported less concentration for penned sows (around 83 nmol/L during the same period). However, one should be careful before drawing conclusions based on comparisons of absolute plasma hormone concentrations because several important factors differ across studies. For example, the stable temperature, the housing environment, the sampling method, the assay used, the genotype, the parity of the experimental animals, and the number of piglets born were different between the studies. The sampling methods used by our study did not increase cortisol to maximum concentrations. It was possible to demonstrate a statistically significant elevated cortisol concentration in the sows exposed to the floor heating relative to the control group.

The changes in periparturient behavior are similar to earlier reports in loose-housed sows at temperatures around 18 to 20°C (Thodberg et al., 2002; Damgaard et al., 2003; Pedersen et al., 2003). In the first period (from −8 to −2 h before farrowing), sows had many postural changes and spent much time walking/standing, but less time in lying laterally. This period may be denoted as the active nest building phase. Then a shift takes place, from about 2 h before farrowing (the late prefarrowing phase), where sows still have many postural changes, but with increased time spent in lateral recumbency. During farrowing and in the early postnatal phase (period 3), sows lie laterally with an overall low activity (the passive phase, from BFP to about 8 h later). In the postnatal period (from 8 to 48 h after farrowing start), the sows spent intermediate time lying laterally and in activity compared with in the more active phase (periods 1 and 2) and the most passive phase (period 3) of the farrowing.

Increased ambient temperatures has been shown to affect behavioral thermoregulation by increasing the time pigs spent lying and decreasing time spent standing and time spent eating (Hyun et al., 2005). Floor heating in the present study did not give rise to increased lying and reduced activity. Neither was the frequency of postural changes increased, which may be a more general behavioral response to stress (e.g., Jarvis et al., 1999). Thus, based on the behavioral observations from 8 h before and until 48 h after farrowing, there was no evidence that floor heating was perceived as a stressor by the sows during the periparturient period. Previous studies reported that sows in pens with a partly heated floor (35°C) had fewer postural changes compared with sows in an unheated pen, whereas their general activity and time spent lying was unaffected by floor heating on the first day of farrowing. This could be interpreted as sows having access to a heated pen.
floor being more comfortable than sows without access to a heated floor (Pedersen et al., 2007). In contrast to studies reporting a positive preference in sows for resting in areas with high temperatures (34 to 35°C) during the first days after farrowing (Phillips et al., 2000; Pedersen et al., 2007), the sows in our experiment were not able to choose between zones with different (e.g., decreased) temperatures because the whole pen floor was equally heated. Postural changes may have some thermoregulatory function with a fully heated floor, but the sows are less able to increase their heat loss from the body surface by lying laterally. Previous studies on thermoregulatory behavior in pigs have been carried out under conditions where only the air temperature has been changed. The thermal demand of the environment is dependent on the ability of the sow to lose heat through evaporation, radiation, conduction, and convection. Thus, the specific challenge of the sows in the present study was that thermoregulation through conduction to the floor surface was not possible. Also, thermoregulation through evaporation after wallowing behavior was reduced because the floor surface was drying faster when heated. Therefore, behavioral thermoregulation through increased lying and reduced activity would probably not be a functional strategy for the sows housed on a heated floor in the present study. We are not aware of any studies comparing thermoregulatory behavior of sows to thermal challenges of different types (e.g., conduction vs. convection heating). The interpretation of the present behavioral data in terms of stress responses would be improved if this knowledge existed. A study conducted under warm and humid climate concluded, based on elevations in body temperatures, that cooling of farrowing sows should be initiated when air temperature reaches 29°C (Dong et al., 2001). However, these results were found under much greater relative humidity (89%) than in the present study (48%).

The plasma oxytocin concentration (measured hourly) increased during farrowing, and maximum concentrations were reached late in the farrowing rather than in the beginning. Plasma oxytocin has been reported to increase as farrowing approach [measured the last 24 h prepartum in Gilbert et al. (2002) and the last 5 h prepartum in Damm et al. (2003)] and also to increase immediately after each fetal expulsion [measured, however, only until 140 min after BFP in Gilbert et al. (1994)]. Thus, the continued oxytocin rise in our study may reflect the accumulation of several fetal expulsions. However, based on frequent blood sampling (with 1-min intervals), the birth-associated contribution to circulating oxytocin due to, for example, cervical stimulation was concluded to be insufficient to account for the mean values in sows, at least when measured during the first part of the parturition (Gilbert et al., 1994). The plasma concentration of oxytocin became increasingly variable in samples obtained as the lactation period proceeded (8 to 24 h after BFP; data not presented), presumably reflecting lactation-induced oxytocin secre-

tion due to piglets suckling/milk ejection (concentration of oxytocin being greater during nursing, e.g., Algers et al. (1990) and Valros et al. (2004)) taking place at different intervals relative to the fixed sampling time for each sows. Piglets of the heat sows had a shorter latency to initiate first suckling (reported in Malmkvist et al., 2006), but we found no difference in the mean oxytocin plasma concentration between HT and CONT sows.

The observed oxytocin increase and peak coincide in our study with the passive phase where sows lie laterally with less overall activity. This posture exposes the udder and thereby allows the piglets to suckle. In addition, this posture is likely to be advantageous because it may reduce the risk of piglet being crushed by the sow (Pedersen et al., 2003).

We found that exposure to heat decreased the between-sow variation of plasma oxytocin and ACTH significantly. Thus, one should not per se assume a homogenous variance structure between treatment groups when analyzing hormone changes around parturition. Whether this decreased variation may be indicative of acute stress or linked to other biological events (e.g., such as the earlier suckling of piglets in the heat treatment) is currently unclear.

In conclusion, temperatures favorable for the neonate piglets gave rise to elevated plasma concentrations of anterior pituitary-adrenocortical hormones (significant for cortisol, a trend for ACTH), but without concurrent changes in mean plasma oxytocin and behavioral activity, in sows around farrowing. At present, we cannot exclude that the exposure of high temperatures (around 33 to 34°C) in the full pen floor act as a stressor in sows around parturition, eventually acting via an increase in their energy metabolism or mobilization during heat exposure. A comparison of the thermoregulatory behavior in periparturient sows subjected to different types of heat challenges would enhance our understanding of the lack of difference in behavioral activity between treatments in the present study.

LITERATURE CITED


Thermal environment during farrowing in sows


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