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Lying behaviour and adrenocortical response as indicators of the thermal tolerance of pigs of different weights

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Abstract

The aim of this study was to assess optimal temperature ranges for fattening pigs of different weights kept in pens with partially slatted floors. We examined the behavioural and adrenocortical responses of pigs of different weights (25–35 kg, 50–70 kg, and >85 kg) to a wide range of ambient temperatures (2–29°C). On three days of each experimental period, we took saliva samples for the analysis of cortisol concentration, and recorded lying behaviour from 0800–0600h. Behavioural and cortisol parameters were analysed using linear mixed effects models. Optimal temperature ranges for the three weight-classes were calculated using logistic regression. Pigs chose different areas for resting depending on ambient temperature. With increasing temperature, pigs used the dung area more often and lay more often without contact with pen mates. Compared to lighter pigs, heavier pigs lay without contact with pen mates at lower temperatures. In general, lying without contact occurred at temperatures 5–7°C lower than lying in the dung area. Huddling increased with decreasing temperature, and, with increasing weight, pigs showed huddling at lower temperatures. There was a significant increase in cortisol levels at high ambient temperatures in pigs >85 kg. In pens with partially slatted floors, the results indicate temperature ranges within the thermal tolerance of pigs to be 19–21°C for pigs weighing 25–35 kg (lying area of 0.46 m^2/pig), 10–17°C for pigs between 50–70 kg and 5–17°C for pigs >85 kg (both weights: lying area of 0.67 m^2/pig).

Keywords: *adaptation, animal welfare, cortisol, lying behaviour, pig, temperature, thermoregulation*

Introduction

In recent years an increasing number of fattening pigs have been kept in un-insulated housing systems. In such systems, pigs have access to outdoor climatic conditions and this has been shown to be beneficial to the animals' welfare (Andersen *et al* 1998; Hauser & Mayer 2001), and is also economical (Bockisch *et al* 1998). However, at extreme ambient temperatures it may be difficult or even impossible for the animals to adapt because pigs are not able to sweat and domestic pigs do not have insulating fur (Ingram 1965). Because of their physiological and morphological inability to adapt to high and low temperatures, domestic pigs cope with ambient temperatures by altering their lying behaviour (Boon 1981; Saellvik & Walberg 1984; Andersen *et al* 1998; Mayer & Hauser 1999). At high temperatures, pigs lie on their sides to expose maximum body surface to the floor, and they avoid body contact with pen-mates (Goetz & Rist 1984; Saellvik & Walberg 1984; Geers *et al* 1986). In addition, they prefer wet places where heat dissipation is high due to conduction. This behavioural adaptation often results in the problem of pigs using the dung area for resting, or urinating and defecating in the lying area to moisten the floor (Geers *et al* 1990). This leads to hygiene problems and impaired air quality as a result of increased emissions of odours and ammonia (Randall *et al* 1983; Olsen 2001). At low temperatures, pigs huddle or even lie upon each other to reduce heat loss to air or floor and to warm themselves with their pen-mates (Boon 1981; Hillmann *et al* 2001). This behavioural adaptation results in disturbance of the animals' resting behaviour (pigs getting up from the bottom or periphery of a huddle displace pen-mates lying above) and an increase in agonistic interactions (Hillmann *et al* 2001). Thus, both at high and at low ambient temperatures, pigs show a behavioural adaptation that can result in disturbed resting behaviour. These behavioural reactions in themselves, or an overtaxing of these behavioural adaptations at extreme temperatures, can lead to physiological stress. Stress reactions of pigs in response to high and low temperatures have been demonstrated in terms of increased plasma or saliva cortisol concentrations (Becker *et al* 1997) and increased oxygen consumption (Geuyen *et al* 1984).

However, until now, most studies on the thermal adaptability of growing finishing pigs have been carried out on

Table 1 Mean body weight (± SD) of weight-classes during experiments.

	Weight class	Weight (kg)	Groups
Summer	LW	29 ± 3.0	1,2,3,4
	MW	59 ± 5.4	1,2,3,4
	HW	88 ± 5.4	5,6,7,8
Winter	LW	35 ± 0.7	9,10,11,12
	MW	51 ± 3.9	9,10,11,12
	HW	91 ± 2.1	9,10,11,12

animals from a particular weight-class or have been performed in climatic chambers quite different from the housing conditions on farms. In addition, there have been few studies that have simultaneously considered behavioural adaptations and physiological reactions of pigs of different weight-classes to a wide range of ambient temperatures. It is well known that in farm animals the thermal tolerance of ambient temperatures is strongly correlated with body weight and related to housing conditions (Bianca 1979; Botermans & Anderson 1995; Becker *et al* 1997; Andersen *et al* 2001), but such studies on the range of tolerated temperatures are rare and have not included animals of different weights (eg Mayer & Hauser 1999).

In the present study we examined the behavioural and adrenocortical responses of fattening pigs from different weight-classes (25–35 kg, 50–70 kg and >85 kg) to a wide range of ambient temperatures (2–29°C) in a commercial pen with a solid concrete lying area and a slatted dung area. Our aim was to use the pigs' behaviour to assess suitable temperature ranges for fattening pigs of different weights. We assumed that: (1) the upper boundary of the optimal temperature range would be marked by a clear increase in resting in the dung area and in lying without physical contact with pen-mates, and the lower boundary would be marked by increased huddling. (2) These boundaries would differ for pigs of different weights, with heavy pigs having a lower boundary both at high and at low temperatures compared to lighter pigs. In addition, we tested whether the pigs showed an adrenocortical response to low and/or high ambient temperatures.

Methods

Animals and housing

Experiments were performed between June 2000 and November 2001 at the Swiss Federal Research Station for Economics and Engineering (Taenikon, Switzerland). Subjects were 12 groups of fattening pigs (Swiss large white; 9 pigs per group; total n = 108). Eight groups were tested in summer at 11–29°C and four groups in winter at 2–19°C.

Experiments were carried out when subjects weighed 25–35 kg (LW), 50–70 kg (MW), and >80 kg (HW) (see Table 1). Subjects were grouped at a weight of 20 kg, and the groups remained stable until slaughtering at approximately 100 kg. The groups were balanced with regard to age, weight, sex and litters. Before the start of the experiments and between experimental periods, pigs were kept in pens comparable to the experimental pens with regard to pen size, structure, climatic and management conditions. Ambient temperatures in these pens ranged between 1–29°C.

During experiments, two groups of pigs were kept simultaneously in two identical pens, separated visually and acoustically from each other in different rooms. Before experiments started, pigs were kept for three to five days in the experimental pens at 18–22°C to adapt to the new environment. Pens had partially slatted floors with a solid concrete lying area of 0.46 m^2 and a slatted dung area of 0.23 m^2 for LW pigs, and a 0.67 m^2 lying area and 0.33 m^2 dung area for MW and HW pigs. The lying area was lightly bedded with straw (100 g/pig/day). Pigs were fed a commercial liquid diet at 0630h and 1630h, and had free access to water. Feeding levels were the same between the experimental periods and between seasons. Outside feeding times the troughs were closed. Pens were cleaned every day during the morning feed. In addition to natural illumination, artificial light was provided between 0600–1700h, and, to aid video recording, dim light was provided between 1700–0600h. During the night, the ventilation was reduced to a minimum or switched off, and windows were opened in order to minimise any background noise within the pen because the animals' vocalisations were recorded during the night (Hillmann *et al* unpublished). The ambient temperature was recorded every 5 mins with data loggers (HOTDOG) fixed on the wall 1 m above the floor in the lying and in the dung areas.

For each weight-class an experimental period lasted 14–17 days. Within each experimental period, in order to cover a wide range of ambient temperatures and to obtain overlapping temperatures in summer and winter, data were collected on three days that were selected based on their ambient temperature being either intermediate (18–20°C both in summer and winter), moderate (summer: 20–24°C, winter: 12–18°C) or extreme (summer: >24°C, winter: <12°C). An additional criterion was that the difference in temperature between two consecutive days had to be less than 4°C. The ambient temperatures in the test pen were achieved by exploitation of outdoor temperature and by using stable heating.

Saliva sampling and analysis of cortisol

Saliva samples were taken on experimental days between 1900–2200h, a time of day at which cortisol levels are usually constant and low (Ruis *et al* 1997; Hillmann *et al* 2001). In order to collect saliva, the subjects were allowed to chew individually on a cotton pad for approximately 30 s. Collecting the saliva samples from all pigs in one group took less than 20 mins and the pigs were not restrained during the procedure. Immediately after collection, the pads were stored in plastic tubes and frozen at –21°C. Prior to analysis, the cotton pads were thawed and centrifuged (3000 rpm at 4°C) to separate the saliva from the pad. Saliva cortisol concentration was analysed using a double antibody radioimmunoassay for the quantitative measurement of cortisol in serum and urine (EURO/DPC®, Gwynedd, UK),

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Table 2 Definitions of behaviours and lying locations.

Behaviour		Description
Lying		
Posture	Huddle	Lying with at least 50% of the body surface having contact with other pig(s)
	Without contact with pen-mates	Lying with less than 10% of the body surface having contact with other pig(s)
Location	Area I	Concrete area at the opposite end of the pen from the dung area (1.25–2.55 m from dung area)
	Area II	Concrete area between Lying Area I and dung area (0–1.25 m from dung area)
	Dung area	Slatted area of the pen
Standing*		Standing, sitting or walking/running
Feeding*		Head in trough around feeding time

* Standing and feeding are mutually exclusive.

which was adapted in our laboratory to analyse cortisol in saliva. The samples (150 μl each) were eluted with 150 μl cortisol antiserum. After incubation for 1 h at 37°C, 160 μl of I^{125}-labelled cortisol were added. After a second incubation (3 h at 37°C), the second antibody was added and the samples were incubated at 20°C for 10 mins and then centrifuged for 30 mins at 4200 rpm and 4°C. The supernatant was removed by suction cleaning, and the radioactivity in the tubes was counted for 1 min (Cobra II, Canberra Packard SA, Zurich, Switzerland).

Lying behaviour

On the three experimental days within each experimental period, behaviour was recorded between 0800–0600h. Lying behaviour and location were recorded by scan-sampling at intervals of 15 mins. The pigs' location within the concrete lying area was recorded as either Lying Area I or Lying Area II (see Table 2) because measurements of the floor conductance had shown that the conductivity increased from Lying Area I to Lying Area II, and to the slatted dung area (Hillmann *et al* 2001). For the definition of behavioural patterns see Table 2.

Statistical analysis

For the behavioural analysis, the mean proportion of animals showing the respective behavioural patterns was calculated separately for day (0800–2000h) and night (2000–0600h). Mean ambient temperatures were calculated over the same time span. Saliva cortisol concentrations were analysed at the level of the individual, and corresponding mean ambient temperatures were determined from the 3 h period prior to saliva sampling.

Due to high outside temperatures during experiments with HW pigs in the first summer period (temperatures were always above 24°C), it was not possible to test HW pigs at neutral ambient temperatures. Therefore the data from these experiments were discarded and the tests were replicated the following year using different subjects. The animals used in the second summer period were of the same type and source (Swiss Large White, bred at the Swiss Federal Research Station for Economics and Engineering), and were kept under the same housing conditions as the animals used in the first summer period. As a consequence, the experimental design was unbalanced and an appropriate statistical analysis had to be used (maximum-likelihood estimator).

We used a linear mixed-effects model to test the fixed effects of ambient temperature (as a covariate), weight-class, and the interaction between these effects on the behavioural parameters and on cortisol concentrations (log-transformed). The factor 'group' (and 'animals in groups' for the analysis of cortisol) was added as a random effect of the intercept to map the hierarchical and incomplete structure of the experimental design. In addition, the model allowed unequal variability between weight-classes within groups (heteroscedasticity). For all calculations, Type III sums of squares were used to test for the fixed effects. All statistics were computed using S-Plus software (version 6.1, release 1).

Because 'lying in the dung area' and 'lying without contact' were almost never observed in the winter period, only data from the summer period were used for the statistical analysis of these parameters. On the other hand, 'huddling' was almost exclusively observed at low temperatures, and therefore only data from the winter period were considered for this parameter.

To determine the boundaries of optimal temperature ranges for pigs in the three weight-classes we performed a logistic regression model. Lying in the slatted dung area and lying without contact were used as behavioural indicators of adaptation to heat, and huddling as an indicator of adaptation to cold. Based on the regression model, the temperature at which 20% of the subjects showed the respective behaviour was calculated. These temperatures were defined as the lower and upper boundaries of the optimal temperature range.

Results

Lying behaviour

Pigs chose to rest in different areas depending on ambient temperature and weight-class (Figure 1). With increasing temperature, less subjects used Lying Area I (temperature: $F_{1,126} = 57.57$; $P < 0.0001$). HW pigs used this area less often compared to MW pigs and LW pigs, and LW pigs used

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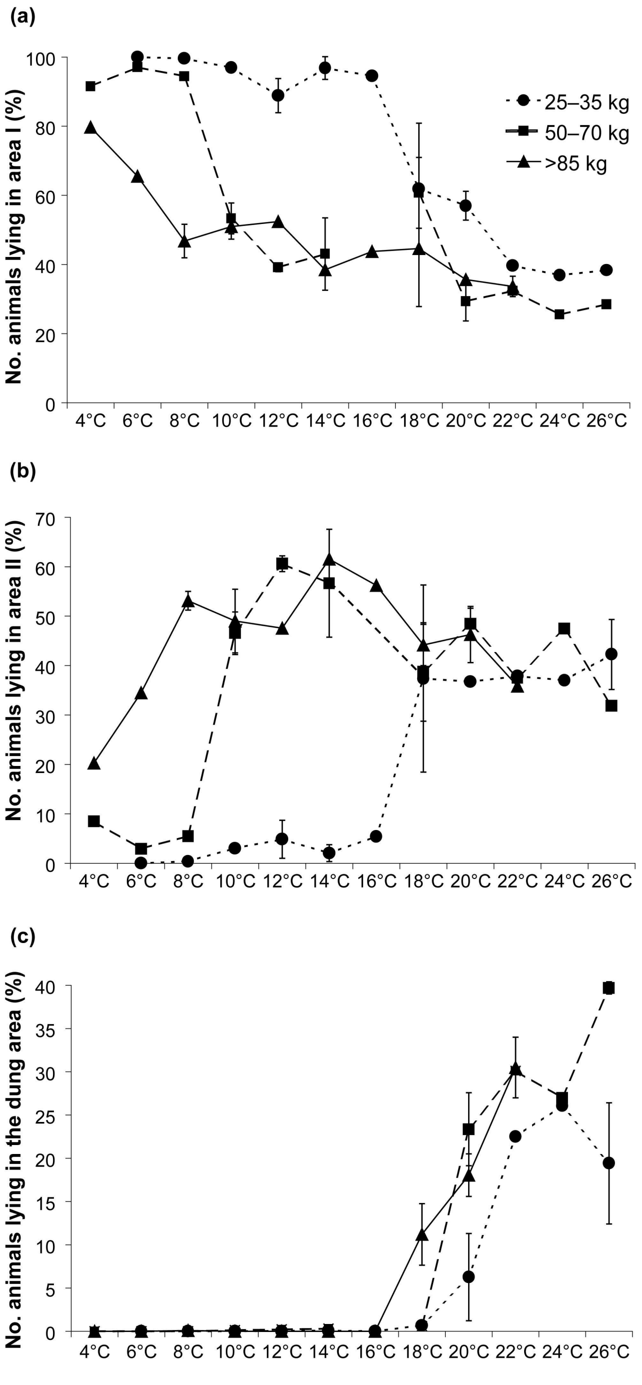
Figure 1



Mean (± SD) % of LW (25–35 kg, circles), MW (50–70 kg, squares) and HW subjects (>85 kg, triangles) lying in (a) Area I, (b) Area II (between Area I and dung area) and (c) dung area (winter period: 4–16°C, summer period: 18–24°C).

Lying Area I the most (weight-class: $F_{2,126}$ = 139.2; $P < 0.0001$). That is, HW pigs began to use the dung area and Lying Area II (adjacent to the dung area) for resting at lower temperatures than did MW and LW pigs (temperature × weight-class: $F_{2,126}$ = 8.4; $P < 0.001$).

HW and MW pigs used Lying Area II most between 10–16°C, while LW pigs began to use this area from 18°C (Figure 1b). This was confirmed by significant effects of temperature, weight-class, their interaction, and a quadratic effect of temperature (temperature: $F_{1,120}$ = 13.95; $P < 0.001$, weight-class: $F_{2,120}$ = 428.59; $P < 0.0001$, temperature × weight-class: $F_{2,120}$ = 11.46; $P < 0.0001$, temperature^2: $F_{1,120}$ = 19.2; $P < 0.0001$, temperature^2 × weight-class: $F_{2,120}$ = 80.6; $P < 0.0001$).

Table 3 Optimal temperature ranges based on the temperatures at which 20% of the animals showed huddling (lower optimal temperature) and lying without contact (upper optimal temperature) (analysed with logistic regression).

Behaviour	LW	MW	HW
Huddling	19°C	10°C	5°C
Lying without contact	21°C	17°C	17°C
Lying in dung area	27°C	23°C	22°C
Optimal temperature range	19–21°C	10–17°C	5–17°C

The dung area was never used for resting during the winter experimental periods. However, during the summer, subjects used the dung area more often with increasing temperature, and this effect again differed between weight-classes (temperature: $F_{1,58}$ = 124.14; $P < 0.0001$, weight-class: $F_{2,58}$ = 76.13; $P < 0.0001$, temperature × weight-class: $F_{2,58}$ = 33.92; $P < 0.001$). HW pigs started to use the dung area at lower temperatures than did MW and LW pigs. LW pigs used the dung area least often.

No more than 40% of subjects were ever observed resting in the dung area (Figure 1c). Based on the logistic regression model, the temperatures at which 20% of the pigs lay in the dung area were 27°C, 23°C and 22°C for LW, MW and HW subjects respectively (Table 3).

The frequency of observed lying postures was also related to ambient temperature (Figure 2). Lying without contact increased with increasing temperature (temperature: $F_{1,58}$ = 80.57; $P < 0.0001$; Figure 2a), and also differed between weight-classes: heavier pigs avoided contact with pen-mates at lower temperatures than did lighter pigs (weight-class: $F_{2,58}$ = 8.97; $P < 0.001$). With regard to lying without contact, the critical upper temperature calculated by logistic regression was 21°C for LW and 17°C for MW and HW subjects. In general, lying without contact was observed at temperatures 5–7°C lower than lying in the dung area (Table 3).

In contrast to lying without contact, huddling increased with decreasing temperature (temperature: $F_{1,63}$ = 14.4; $P < 0.001$; Figure 2b). With increasing weight, subjects were observed huddling at lower temperatures (weight-class: $F_{2,63}$ = 277.71; $P < 0.0001$, weight-class × temperature: $F_{2,63}$ = 54.07; $P < 0.0001$). During the summer, only LW subjects showed huddling. For huddling, lower critical temperatures were 19°C, 10°C and 5°C for LW, MW and HW subjects respectively (Table 3).

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Cortisol

Ambient temperatures affected cortisol concentrations differently for animals of different weight-classes (Figure 3). In LW and MW pigs, concentrations of cortisol remained unchanged at all temperatures, while in HW pigs concentrations increased with increasing temperature. At temperatures above 13°C, saliva cortisol concentrations were higher in HW pigs than in MW and LW pigs (temperature: $F_{1,856} = 4.49$; $P < 0.05$, weight-class: $F_{2,856} = 33.25$; $P < 0.0001$, weight-class × temperature: $F_{2,856} = 15.4$; $P < 0.0001$).

Discussion

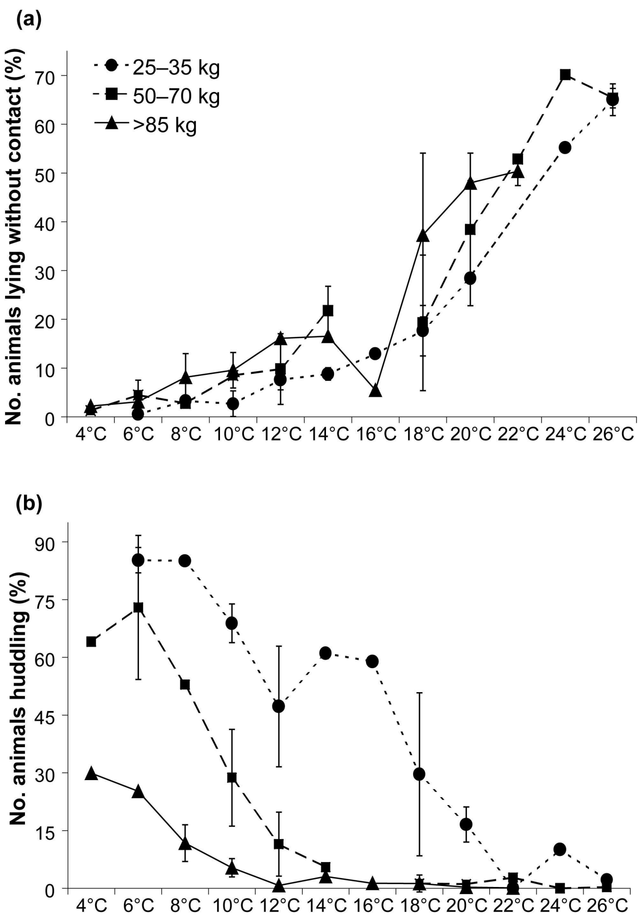
Based on analysis of the lying behaviour and saliva cortisol concentrations of fattening pigs, we have quantitatively identified optimal thermal ranges for pigs of different weights kept under farm conditions in pens with partially slatted floors. Both the lower boundary and the upper boundary of the optimal thermal range decrease with increasing pig weight. Moreover, light pigs showed a remarkably narrower range of thermal tolerance than heavy pigs.

Lying behaviour

In the pens used in our study, the lying area showed continuously increasing conductivity from Area I (at the opposite end of the pen to the dung area) to Area II (next to the dung area) (Hillmann *et al* 2001). Correspondingly, with increasing ambient temperature, the pigs preferred Area II for resting and lay less in Area I. However, when temperatures were above 16°C, MW and HW pigs began to rest more in the dung area and less in Lying Area II.

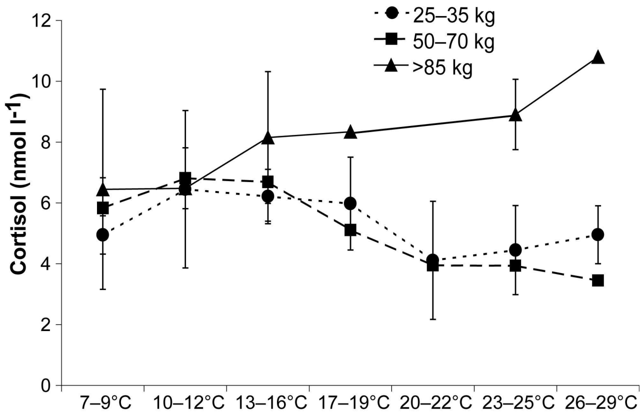
The concrete areas of the partially slatted pens were preferred at temperatures up to 27°C by LW pigs, 23°C by MW pigs, and 22°C by HW pigs. Above these ambient temperatures, subjects rested in the dung area. The slatted floor in the dung area offers a much higher conductivity compared to the concrete floor of the lying area (Hillmann *et al* 2001), and can be used by fattening pigs to increase heat loss at high temperatures (Randall *et al* 1983). Since pigs prefer a dry and clean lying area, lying in the dung area indicates an attempt to cope with heat and is a sign of thermal discomfort (Geers *et al* 1990; Jones *et al* 1999). In addition, lying in the dung area is a problem with respect to hygiene and emissions (Randall *et al* 1983; Olsen 2001). It might seem surprising that in our study a maximum of 40% of the pigs lay in the dung area. However, this was the highest possible proportion because the dung area of 2.94 m^2 did not offer enough space for more animals. Because of their greater need for heat loss, pigs with higher weights used the dung area at lower temperatures. With increasing ambient temperature, the subjects also avoided body contact with pen-mates, ie lying without contact with pen-mates increased. Again, the temperature at which subjects showed this behaviour was higher for LW subjects (21°C) than for MW and HW subjects (both 17°C).

Figure 2



Mean (± SD) % of LW (25–35 kg, circles), MW (50–70 kg, squares) and HW subjects (>85 kg, triangles) (a) lying without contact with pen-mates, and (b) huddling (winter period: 4–16°C, summer period: 18–24°C).

Figure 3



Mean (± SD) saliva cortisol concentrations for LW (25–35 kg, circles), MW (50–70 kg, squares) and HW subjects (>85 kg, triangles) measured between 1900–2200h (winter: 6–16°C, summer: 17–29°C).

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During resting, especially at night, pigs often have contact with members of their social group (Stolba & Wood-Gush 1989; Ekkel *et al* 2003). However, at high ambient temperatures, pigs can achieve greater heat loss by avoiding physical contact with each other (Bianca 1979; Saellvik & Walberg 1984). Thus, we consider lying without contact to be an indicator of the animals' attempts to cope with increasing ambient temperature. The boundaries for lying without contact with pen-mates were lower than the temperatures at which the subjects started to use the dung area for resting. This indicates that pigs lay in the dung area when thermal adaptation by lying without contact did not suffice. Alternatively, the pigs may have preferred to lie without contact instead of lying in the dung area, but a lying area of 6 m^2 would not have provided all pigs with the opportunity to lie without contact with pen-mates (the floor area occupied by a lying pig of 80 kg is approximately 0.64 m^2 [Ekkel *et al* 2003]). Thus, the animals have to rest in the dung area both to avoid contact with pen-mates and to increase heat loss through heat dissipation.

In winter, subjects started huddling when temperatures decreased. This behaviour was observed when ambient temperatures were below 19°C for LW pigs, 10°C for MW pigs, and 5°C for HW pigs. Huddling is a well known adaptation to low temperatures because subjects can reduce heat loss to the air or floor and can profit from the heat radiation of pen-mates (Boon 1981; Botermans & Anderson 1995). However, this behaviour results in disturbed resting behaviour and can lead to an increase in agonistic interactions (Hillmann *et al* 2001). Thus, a high proportion of pigs huddling might indicate that their behavioural adaptability has been exceeded.

Cortisol

In summer, at temperatures above 13°C, the adrenocortical activity of pigs >85 kg was higher than that of pigs <70 kg, and the cortisol concentrations of HW pigs increased with increasing temperature. Consistent with our results, Becker *et al* (1997) reported an increase in plasma cortisol concentration when gilts weighing 120 kg were exposed to 34°C in a climatic chamber. There was no adrenocortical response to high ambient temperatures in MW and LW pigs. However, pigs >85 kg are known to be more sensitive to elevated temperatures compared to lighter pigs (Botermans & Anderson 1995). In addition, the pens used in our study were situated in large chambers so that the animals were provided with high volumes of fresh air, and, in part, subjects had the opportunity to select lying places with a higher conductivity (dung area) as already discussed. Thus, the climatic conditions in the study of Becker *et al* (1997) are likely to have been more extreme than those in the present study.

We did not find increased concentrations of cortisol at low ambient temperatures in winter. This is in contrast to Becker *et al* (1997), who found an increased secretion of cortisol when pigs weighing 110 kg were exposed to an ambient temperature of 10°C. However, in contrast to our experiments, Becker and co-workers tested their pigs individually in a climatic chamber, whereas the subjects in our experiments were able to warm mutually (ie by lying in body contact or by huddling) — such a behavioural adaptation was not possible for the pigs studied by Becker *et al* (1997). Thus, even the lower ambient temperature of 4°C in our study, to which we exposed pigs of 35 kg, might have been less extreme than conditions in the climatic chamber of Becker *et al* (1997), in which the pigs had no opportunity for social thermoregulation.

For the growing finishing pigs >85 kg, the elevated temperatures during summer led to a significant increase in salivary cortisol. Together with the behavioural reactions, we may therefore conclude that the animals' ability to adapt to high temperatures was overtaxed. On the other hand, there was no temperature-dependent change of cortisol concentration for pigs <70 kg in summer, and no adrenocortical response during winter, although the animals showed clear behavioural reactions (huddling).

Animal welfare implications

From our results, the optimal temperature ranges for fattening pigs of different weight-classes can be derived. The range of thermal tolerance was wider for heavy pigs than for light pigs, confirming that light pigs are much more sensitive to changes in ambient temperature. In addition, our study demonstrates that misuse of the dung area in pens with partially slatted floors can be avoided if the pigs' requirements for ambient temperature are fulfilled. These results are also relevant to the Directives of the European Communities (2001/88/EC and 91/630/EEC) concerning the minimum standards for the protection of pigs, which are due to be revised by 2007. Therein, in particular, the relationship between climatic conditions and flooring types are to be considered.

We did not find an adrenocortical reaction to exposure to low ambient temperatures, but, in the summer period (17–29°C), pigs >85 kg showed increased cortisol levels. This may indicate that growing finishing pigs are especially sensitive to elevated ambient temperatures, which can easily occur both in insulated and un-insulated housing during the summer.

To summarise, with respect to the animals' welfare, the behavioural adaptation of pigs should be considered further in order to assess their ranges of thermal tolerance. Although saliva cortisol concentration was found to be an appropriate indicator of heat stress in growing finishing pigs, our study suggests that behavioural indicators — ie allowing the pigs to show their species-specific and undisturbed resting behaviour — offer a more sensitive means of assessing optimal thermal ranges. Our results support the findings of other authors that, with regard to animal welfare, in insulated as well as un-insulated housing, low ambient temperatures should be compensated for by offering a greater amount of straw and/or by providing insulated kennels which offer microclimatic areas. At high temperatures, the lying area should offer sufficient space for all pigs to lie laterally without contact with pen-mates. Also, additional opportunities to cool down (eg sprinklers) could be installed.

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