The environmental requirements of piglets and use of the creep area

(Spedgrisens miljøkrav og bruk av spedgrishjørnet)

Philosophiae Doctor (PhD) Thesis 2010:47

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ISBN: 978-82-575-0957-6

ISSN: 1503-1667

One day a man was walking along the beach when he noticed a girl picking something up and gently throwing it into the ocean. Approaching the girl, he asked, “What are you doing?” The youth replied, “Throwing starfish back into the ocean. The surf is up and the tide is going out. If I don’t throw them back, they’ll die.” “Child,” the man said, “don’t you realize there are miles and miles of beach and thousands of starfish? You can’t make a difference!”

After listening politely, the girl bent down, picked up another starfish, and threw it back into the surf. Then, smiling at the man, she said…”I made a difference for that one.”

– Lauren Eisley

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ABSTRACT

Vasdal, G., 2010. The environmental requirements of piglets and use of the creep area. Philosophiae Doctor Thesis 2010:47, Norwegian University of Life Sciences, Department of Animal and Aquacultural Sciences.

Around 15% of all liveborn piglets die during the lactation period, and this poses a major economical and welfare challenge for the pig production. It has been hypothesized that an increased use of the creep area early after birth will reduce piglet mortality as it provides the piglets with heat and protection from crushing. The aim of this thesis was to investigate environmental requirements and preferences in newborn piglets, and to use this information in an attempt to design a more attractive piglet creep area. Furthermore, we wanted to test the hypothesis that a more attractive creep area would increase the use of the creep area, and reduce piglet mortality. The results showed that piglets were increasingly capable of using thermoregulatory behaviours like posture changes and to a lesser extent, degree of huddling, in order to adapt to changes in the thermal environment, but these strategies were not fine tuned at birth. The thermoregulatory behaviors affected the space occupied by a resting litter, and the creep area must be 1.26 m^2 in order to accommodate 14 piglets at three weeks of age. In the 60 minute preference test, the piglets preferred to rest in 42 ºC, and in a thick layer of sawdust. Piglets in crates spent more time in the creep area compared to piglets in pens. However, the piglets still chose to rest near the sow when a creep area large enough for the whole litter, containing high infrared temperatures and a thick layer of sawdust was presented in the farrowing pen. The findings from this thesis indicate that piglets are able to assess and adjust to their thermal environment and that they have clear preferences for high infrared temperatures. However, our results also show that quality of the creep area does not increase time spent in the creep area when the sow is present, and more importantly; increased time spent in the creep area does not reduce piglet mortality.

ISBN: 978-82-575-0957-6

ISSN: 1503-1667

SAMMENDRAG

Vasdal, G., 2010. The environmental requirements of piglets and use of the creep area. Philosophiae Doctor Thesis 2010:47, Universitetet for Miljø og Biovitenskap, Institutt for Husdyr og Akvakulturvitenskap.

Rundt 15 % av alle levendefødte gris dør før avvenning, og dette er en stor utfordring for svinenæringen, både etisk og økonomisk. Man tenker seg at dersom spedgrisen bruker det varme spedgrishjørnet i bingen i en større grad tidlig etter fødsel, kan flere overleve grunnet et lavere varmetap og mer beskyttelse fra å bli ligget på av purka. Målet med denne avhandlingen var å undersøke spedgrisens miljøkrav og preferanser, og ved hjelp av denne kunnskapen utvikle et mer attraktivt spedgrishjørne. Vi ønsket også å undersøke om et mer attraktivt spedgrishjørne kan øke bruken av hjørnet tidlig etter fødsel, og om økt bruk kan redusere spedgristapet. Resultatene viste at spedgris er i stand til å tilpasse seg det termiske miljøet ved å endre sin individuelle liggepositur og, i en mindre grad, nærhet til kullsøsken, og at disse strategiene blir bedre utviklet med alder. Siden temperaturen påvirker spedgrisenes liggemønster, påvirket også temperaturen hvor stor plass et kull med spedgris opptok, og et spedgrishjørne med plass til 14 smågris ved tre uker bør være minimum 1.26 m^2 for at hele kullet skal få ligge samtidig. I preferansetesten foretrakk spedgrisene 42 ºC, og et tykt lag med sagflis fremfor andre temperaturer og liggeunderlag, men når disse to stimuliene ble kombinert i et spedgrishjørne med plass til alle, valgte de fortsatt å ligge hos purka. Spedgris i fikseringsbinger tilbrakte mer tid i hjørnet enn spedgris i løse binger. Resultatene fra denne avhandlingen viser dermed at spedgris er i stand til å vurdere, og tilpasse seg sitt termiske miljø, og at de har en klar preferanse for høye temperaturer og sagflis. Samtidig fant vi at selv om vi tilbyr spedgrisen et tilsynelatende attraktivt hjørne basert på disse preferansene, fortrekker de fortsatt å ligge hos purka de første dagene etter fødsel. Og kanskje ennå viktigere; vi fant at økt tid brukt i spedgrishjørnet ikke hadde noen sammenheng med spedgrisdødeligheten.

ISBN: 978-82-575-0957-6

ISSN: 1503-1667

List of papers

This thesis is based on the following papers referred to by their roman numerals in the text:

Paper I:

Vasdal, G., Wheeler, E. F., Bøe, K. E., 2009. Effect of infrared temperature on thermoregulatory behaviour in suckling piglets. *Animal* 3, 1449-1454.

Paper II:

Wheeler, E.F., Vasdal, G., Flø, A., Bøe, K.E., 2007. Static space requirements for piglet creep area as influenced by radiant temperature. *Transactions of the ASABE*, 51 (1): 271-278.

Paper III:

Vasdal, G., Møgedal, I., Bøe, K. E., Kirkden, R., Andersen I.L., 2010. Piglet preference for infrared temperature and flooring. *Applied Animal Behaviour Science*, 122, 92-97.

Paper IV:

Vasdal, G., Pedersen, L. J., Andersen, I. L., 2009. Piglet use of creep area – effect of breeding value and farrowing environment. *Applied Animal Behaviour Science*, 120, 62-69.

Paper V:

Vasdal, G., Glærum, M., Melišová, M., Bøe, K. E., Broom, D. M, Andersen I.L., 2010. Increasing the piglets' use of the creep area – A battle against biology? *Applied Animal Behaviour Science* 125, 96-102.

1. Introduction

1.1. General introduction

More than 1 billion domestic piglets are born every year worldwide (e.g. Cameron, 2000), and more than 1 million of them are born in Norway (Norsvin, 2008). Piglet mortality is a major economical and ethical challenge for the swine industry, and in Norway, where all sows are loose housed, 14.8 % of all live-born piglets die before weaning (Norsvin, 2008). In the UK, 11.8 % of the liveborn piglets die before weaning (75 % crated sows) (e.g. Baxter et al., 2008) while 14 % of the liveborn piglets die in Denmark (around 98 % crated sows) (Videncenter for svineproduktion, 2009). The farrowing crate was developed in the sixties to reduce piglet mortality, but several studies have reported similar mortality in crates and pens (e.g. Biensen et al., 1996; Cronin et al., 2000; Weber et al., 2007, Pedersen et al., 2008).

Most of the piglet mortality occurs within 48 hours after farrowing (e.g. Dyck and Swierstra, 1987; Andersen et al., 2005), and around 80 % of the postnatal mortality can be explained by hypothermia, starvation and crushing by the sow (English, 1993; Marchant et al., 2001). Contrary to most mammals are piglets born without brown adipose tissue and fur for insulation, and newborn piglets are vulnerable for hypothermia at temperatures below 34 ºC (e.g. Berthon et al., 1993; Lossec et al., 1998). The farrowing unit is kept at 20 ºC for the sows comfort, and the creep area in the pen is meant to provide the piglets with a suitable microclimate in addition to physical protection from the sow, and it is commonly assumed that piglet survival will increase if the piglets start using the creep area from an early age.

1.2. Important aspects of maternal behaviour in relation to piglet mortality

Maternal behaviour in domestic sows is similar to that of the wild boar (e.g. Jensen, 1986; Gustavsson et al., 1999), and when given the opportunity, the sows will leave the group to search for a suitable nest site 1-2 days prior to farrowing (e.g. Jensen et al., 1987a; 1993; Jensen, 1989). When the sow finds a suitable location, she builds a farrowing nest to protect her piglets from predators and unfavourable climate, typically spending 5-10 hours on the construction of the nest (e.g. Wood-Gush and Stolba, 1982; Jensen et al, 1993), and similar activity patterns are documented in commercial housing systems (e.g. Andersen et al., 2005; Vasdal et al., in prep). During early parts of the farrowing process, the sow often grunts regularly and sniffs the first piglets that are born (e.g. Jensen, 1986) but remains passive throughout most of the farrowing process, with little maternal care towards her piglets. This behaviour is positive for piglet survival as a passive sow is less likely to injure or crush her offspring than a sow who have frequent posture changes during the farrowing process (e.g. Fraser, 1995; Jarvis, 1999).

The sow will spend most of her time in the nest the first two days after farrowing and will only leave her piglets for brief foraging trips, both in semi-natural conditions (e.g. Jensen, 1986; Stangel and Jensen, 1991) and in commercial get-away pens (e.g. Arey and Sancha, 1996; Pajor et al., 2000). The piglets spend this period resting in close contact with the sow and littermates, leaving the nest only to defecate (Stangel and Jensen, 1991). Remaining in the nest after birth is important for piglet survival in several ways: it facilitates the development of the mother-young bond (e.g. Jensen and Redbo, 1987) and reduces the chance of the sow and piglets becoming separated from each other. It may also reduce the chance that the piglets are detected by predators and it provides protection against cold weather (Algers and Jensen, 1990). Another important aspect of remaining close to the sow is that the piglets gain warmth and food from the udder (e.g. Fiala and Hurnik, 1983). The sow and piglets are thus motivated to remain close to each other during the first days after farrowing.

Maternal ability can be defined as the ability of a sow to enhance the fitness and survival of her offspring through her behaviour (Fleming et al., 1996). The maternal ability of sows vary between individuals, and sows with low piglet mortality are generally known to be more responsive to piglet vocalizations, have more nose contact with the piglets around posture changes, and show reduced activity around farrowing and the first period in lactation (e.g. Andersen et al., 2005; Burri et al., 2009; Wischner et al., 2010). The sows maternal behaviour will also be influenced by the environment, as the crate physically impair the sow's ability to move and interact with her piglets. Sows housed in loose house pens display more piglet-directed behaviour, higher responsiveness to piglet screams, increased nest building behaviour and increased nursing behaviour compared to sows in crates (e.g. Cronin and Smith, 1992; Cronin et al., 1996; Arey and Sancha, 1996; Damm et al., 2003). An increased responsiveness towards the piglets and a higher piglet survival is also documented in litters where the sow can regulate the contact with the offspring, such as in get-away pens (Pajor et al., 2000; Pitts et al., 2002).

Sows often show a consistency in their maternal abilities across parities, both with regards to piglet crushing (Jarvis et al., 2005) and response to piglet scream tests (Held et al., 2006; 2007). The relationship between response to screams and piglet mortality has been confirmed in experimental herds (Wechsler and Heggelin, 1997; Andersen et al., 2005), but not in commercial herds (Spinka et al., 2000; Grandinson et al., 2003; Held et al., 2007). Increased sow parity is documented to reduce both sow response to piglet screams (e.g. Thodberg et al., 2002; Vieuille et al., 2003; Held et al., 2006) and to reduce piglet survival (e.g. Weary et al., 1998; Weber et al., 2009). The reduction in maternal investment with increasing parities may be due to age-related changes in resource exploitation as sows get less efficient at converting food into milk, and thus the costs of nursing increases with age (Evans, 1990; Held et al., 2006). An additional explanation may be that sows, at least in Norway, are selected for increased number of live born in the first three parities (Norsvin Breeding Goal, 2009), which may result in an over-investment in the first litters, and a subsequent depletion of available resources for later litters.

In order to get more and faster growing piglets per litter, the domestic pig has been selected for traits such as increased litter size, faster growth and reduced backfat thickness. But, there are several negative effect of this selection, including increased leg weakness in adult animals, reduced sow longevity, increased number of lighter and immature piglets at birth and a larger variation in birth weight (Rauw et al., 1998; Jorgensen and Andersen, 2000; Holm et al., 2004; Canario et al., 2007; Prunier et al., 2010). In addition, large litter size is also associated with a reduction in maternal responsiveness to piglet screams (Wechsler and Hegglin, 1997; Torsethaugen, 2008), and reduced time spent with the offspring in mice (e.g. Priestnall, 1972). Since maternal behaviour influence piglet survival, there is a need to develop ways to score and possibly select for maternal behavioural traits directly.

Selection for improved maternal ability directly has been achieved in mice by developing and selecting for a ‘maternal care index’, including nest building, nursing and licking (Chiang et al., 2002a) and a similar breeding goal in sows may help to reduce piglet mortality, even in large litters (Chiang et al., 2002b; Grandinson et al., 2005). Selection for increased number of liveborn piglets in Landrace sows has resulted in increased piglet mortality (e.g. Lund et al., 2002), but despite this negative correlation, number of liveborn piglets is still 22 % of the breeding goal for Landrace in Norway (Norsvin Breeding Goals 2009). On the other hand, breeding for number of live piglets at day 5 after birth (ND5) has been selected for in all Danish breeding herds since 2004, and this trait is positively correlated with piglet survival (Su et al., 2007). However, when selecting sows based on their breeding value for ND5, it is difficult to know whether any increase in survival is achieved through improved maternal abilities, the prenatal environment, factors related to the birth process or a combination of many factors.

1.3. Piglet mortality

Contrary to most domestic animals, the sow gives birth to a large number of precocial offspring, with variable birthweight. The evolutionary strategy of the pig is to produce more offspring than is expected to survive, where the strongest and heaviest piglets will win access to the teats, and their lighter siblings often die unless conditions are very favourable (e.g. England, 1986; Pluske et al., 1995). A strategy like this, which is common in polytocus species, requires less prenatal and postnatal maternal investment per offspring compared to species like cattle and sheep that show more maternal care towards each offspring (e.g. Varley, 1995). Farmed wild boar is reported to have an average littersize of 4.5, ranging from 1 to 12, where around 40 % of the liveborn piglets die (Lands Management Personnel and

U.S. Forest Service, 1990). The domestic sow, on the other hand, has an average litter size of 12.5, ranging from 4 to more than 20 liveborn, where around 10 – 15 % of the piglets die (e.g. Norsvin, 2008; Videncenter for svineproduktion, 2009). In this perspective, one could argue that the domestic sow is in fact extremely successful in weaning a large number of offspring, and it is not surprising that the swine industry struggles to further reduce the piglet mortality.

Piglet mortality is a vastly complex problem and 80 % of the mortality occurs during the perinatal period, that is, during farrowing and the first three days after birth (e.g. English and Morrison, 1984; Svendsen, 1992). Between 3 – 8 % of all piglets are stillborn, and of these, 10% dies shortly before farrowing, 75% during farrowing and the remaining 15% immediately after farrowing (e.g. Vanderhaeghe et al., 2009). The causes of stillbirth are still not fully understood, but some of the stillbirths may be due to intrauterine factors, such as reduced placental efficiency, reduced uterine blood flow or asphyxia during the farrowing process (e.g. Alonso-Spilsbury, 2005; Canario et al., 2007; Baxter et al., 2008; Oliviero et al., 2010). The death of a liveborn piglet can be caused by one or more interacting factors; prenatal factors, piglet characteristics such as body shape and size, birthweight, birth order, litter size and vitality at birth, maternal behaviour, the thermal environment and management around farrowing (e.g. Hartsock and Graves, 1976; Tuchscherer et al., 2000; Andersen et al., 2005; Baxter et al., 2008; Andersen et al., 2009; Vasdal et al., in press; Pedersen et al., submitted).

Early colostrum intake is vital in order to acquire passive immunity (e.g. Rooke and Bland, 2002; Le Dividich et al., 2005) and to improve thermoregulation and increase the survival rate in newborn piglets (e.g. Gentz et al. 1970; Noblet and Le Dividich, 1981; Herpin et al., 1994). A short latency from birth to the first suckling will increase the survival chance for a piglet, and latency depends on birth weight, vitality at birth, number of piglets already present at the udder and number of sow posture changes (e.g. Parfet and Gonyou, 1988; Hoy et al., 1995; Tuchscerer et al., 2000; Milligan et al., 2002; Vasdal et al. in press). For example, a lightweight piglet born late in the litter will often lose the fights for teats to their earlier born (e.g. Baxter et al., 2009) and heavier siblings (e.g. Milligan et al., 2002), rendering them hungry, cold and with a reduced vitality (e.g. Le Dividich and Noblet, 1981). These piglets tend to remain close to the sows' udder outside the time of nursing, and are more likely to get crushed by the sow (Scheel et al., 1977; Weary et al., 1996a; 1998).

Breeds such as the Norwegian Landrace are, as previously mentioned, selected for number of liveborn and low backfat thickness, which results in increased birth weight variability, a higher number of low birthweight piglets, less mature pigs at birth and a reduced survival rate (e.g. Herpin et al., 1993; McKay, 1993; Milligan et al., 2002; Canario et al., 2007). In addition to the negative effects of low birth weight on the competitive ability and survival rate in the newborn piglet, low birth weight is also linked with pathological conditions like delayed maturation of both the digestive system (Thornbury et al., 1993) and the endocrine system (Wise et al., 1997). Large littersize also result in a higher drop in rectal temperature after birth (Tuchscherer et al., 2000), more piglets not getting access to a teat during milk letdown (Andersen et al., accepted), a lower weight gain during the lactation period (Lundgren et al., 2010) and a higher mortality (e.g. Weber et al., 2009), especially due to starvation or crushed piglets with starvations as the primary cause (Andersen et al., accepted). On top of that, Devillers et al. (2007) found that although milk production throughout the lactation increases with litter size, colostrum production does not, resulting in less colostrum being available for each piglet in large litters.

Several measures have been taken over the years in order to reduce piglet mortality, and lactating sows are housed in crates throughout most of the world in order to reduce piglet crushing. Fewer piglets do get crushed in these systems compared to loose housed pens, but rather than getting crushed, piglets die of other causes in the crates, resulting in similar mortality in the two systems (e.g. Biensen et al., 1996; Cronin et al., 2000; Weber et al., 2007; 2009; Pedersen et al., submitted). Knowing that it can take over 7 hours for a piglet to reach a teat after birth (e.g. Vasdal et al., in press), it is important to reduce the heat loss after birth, and subsequently, perhaps reduce the time from birth to colostrum intake. Several management routines are documented to reduce piglet mortality, such as supervision of the farrowings and provision of oxygen, giving milk and fluids orally or tying the umbilical cord (e.g. Holyoake et al., 1995; White et al., 1996; Herpin et al., 2001). Another efficient and simple way of reducing the heat loss after birth is to dry the piglets and place them underneath the heat lamp, which alone can reduce piglet mortality by 6-8 % (McGinnis et al., 1981; Christison et al., 1997; Andersen et al., 2009; Vasdal et al., in press). Helping piglets to get colostrum after birth by placing them near the udder has improved piglet survival in commercial loose-housed sow herds (Andersen et al., 2007).

1.4. Thermoregulation in the newborn piglet

Piglets are born without fur or brown adipose tissue for insulation, rendering them vulnerable for hypothermia (e.g. Berthon et al, 1994; Herpin et al., 2002). Hypothermia is a physiological condition where the core temperature drops below that required for normal metabolic activity, and this condition can be due to exposure to excessive cold, reduced heat production ability or a combinations of these (Herpin and Le Dividich, 1995). Hypothermia in piglets can be the direct cause of death, or it can be a predisposing factor for other causes of death, as hypothermic piglets are less vital, less able to compete for colostrum or vacate the danger zone near the sow when she lies down (e.g. Edwards, 2002, Malmkvist et al., 2006; Baxter et al., 2008; Pedersen et al., 2008; Vasdal et al., in press; Pedersen et al., submitted).

The lower critical temperature (LCT) for an animal can be defined as the temperature where the animal has to increase its heat production in order to maintain body temperature, while the absolute lower critical temperature is where the metabolic rate reaches its peak (e.g. Curtis, 1983). The LCT for newborn piglets is recognized to be around 34 ºC (e.g. Berthon et al., 1993; Lossec et al., 1998), while the ambient temperature in most farrowing units is kept within the sows' thermoneutral zone, around 20 ºC. This is clearly suboptimal for the piglets, and can lead to more than 2 ºC drop in piglet body temperature during the first 20 minutes after birth (Lossec et al., 1998; Herpin et al., 2002). As some piglets need up to 48 hours to recover a normal body temperature after birth, it is not surprising that a majority of the piglet mortality occur during this period.

The extent of the heat loss and recovery rate differs among individual piglets, and is dependent on the physiological condition of the piglet, such as immunological state (Herpin et al., 2002), colostrum intake (e.g. Gentz et al., 1970) and birth weight (e.g. Le Dividich and

Noblet, 1981; Herpin et al., 2004; Herpin and Le Dividich, 1995). The thermoregulatory capacity improves with age, and LCT is reduced to 30 ºC at 48 hours in piglets that have received colostrum (e.g. Berthon et al., 1994). In order to increase their body temperature, piglets depend on energy demanding muscular shivering thermogenesis; however, as their heat producing ability is low and they have low innate energy reserves, colostrum intake is essential to maintain this thermoregulatory activity and to achieve thermoregulatory stability (e.g. Gentz et al., 1970; Noblet and Le Dividich, 1981).

Newborn piglets can also adapt to their thermal environment through reducing their heat loss by means of social thermoregulation, and a huddling litter of newborn piglets can reduce their lower critical temperature (LCT) from 34 to 25-30 °C (e.g. Mount, 1979). Newborn piglets often huddle close to the udder that has a surface temperature of 38 ºC after farrowing (Fiala and Hurnik, 1983). Another strategy adopted by piglets in suboptimal temperatures is individual thermoregulation; the heat loss to the floor is reduced through the adoption of a sternum posture from a recumbent posture (e.g. Mount, 1967; Baxter, 1984). Several studies have investigated the effects of temperature on lying behaviour and space occupation in older, heavier pigs (e.g. Ekkel et al., 2003; Hillmann et al., 2004; Huynh et al., 2005; Pastorelli et al., 2006), but few have focused on the ontogeny of these two strategies, or on how these thermoregulatory behaviours are affected by weight, age and the ambient temperature in young piglets.

1.5. Environmental preferences and piglet use of the creep area

Opposite to what is observed under natural conditions, where the sow leaves the piglets in the nest, modern farrowing systems are based on the idea that newborn piglets should leave the sow and enter the heated creep area in the farrowing pen. The creep area is meant to supply an optimal thermal environment for the piglets within the farrowing pen, and heat sources, either floor heating, infrared heater or both, provides a suitable microclimate. The floor area in the creep area is variable in size and seems to be rather informally determined by construction convenience, and the size of the creep area is often not sufficient to accommodate the whole litter at once. In an undersized creep area, weaker piglets may be forced to rest in areas where they are potentially chilled, and if outside the protected area, it is hypothesized that they suffer a higher risk of being crushed. Based on the body measurements of 109 piglets, Moustsen and Poulsen (2004a) calculated a space requirement of 0.8 m^2 in the creep area to accommodate 10 piglets, and 1.28 m^2 at five weeks (Moustsen and Poulsen, 2004b), but the authors suggest to supplement these calculations by photographic determinations of the actual space occupied by the piglets.

Many studies have investigated piglet preferences in order to stimulate the piglets to use the creep area (e.g. Zhang and Xin, 2001; Lay et al., 1999; Schormann and Hoy, 2006). Newborn piglets that have been taken away from the pen to a test arena are attracted to high temperatures (e.g. Hrupka et al., 2000a), to maternal odours and vocalizations (e.g. Morrow-Tesch and McGlone, 1990; Parfet and Gonyou, 1991) to soft and warm surfaces (e.g. Welch and Baxter, 1986) and to dim or dark areas (e.g. Parfet and Gonyou, 1991). By exploiting piglets' attraction to such stimuli, attempts have been made to increase the use of the creep area when the sow is present in crates, either by reducing temperature in the sow area (Zhou and Xin 1999; Schormann and Hoy, 2006), by adding a warm water bed in the creep area (Ziron and Hoy, 2003) or by providing a simulated udder (i.e. a soft, warm surface with sow odour) in the creep area (Lay et al., 1999; Toscano and Lay, 2005). Although several of these studies report a preference for certain stimuli in the creep area, they have either presented time spent in the creep area when the sow is standing, or the observations started at day 3 after birth, or they report that piglets spent about 50 % of their time in the creep area, which is similar to what is reported in studies of loose housed sows (Berg et al., 2006). None of these studies rapport any effects on piglet survival as an effect of time spent in the creep area. A relationship between piglet survival and time spent in the creep area has actually never been documented.

Few, if any studies have been able to attract newborn piglets away from the sow in a loose housed setting. In fact, numerous studies have found that young piglets prefer to huddle near the sow and littermates the first days after birth, despite unfavourable thermal conditions in the sow area (e.g. Hrupka et al., 1998; Berg et al., 2006; Moustsen et al., 2007). Hrupka et al. (2000b) found that piglets were more attracted to an anesthetized piglet in a cold area than to an empty warm area, clearly indicating that the attraction to heat is weaker than the attraction to littermates. The piglets usually starts using the creep area from day 3 after birth (e.g. Hrupka et al., 1998; Berg et al., 2006), which is the age when they would naturally start exploring the nest surroundings together with the sow (e.g. Stangel and Jensen, 1991).

Piglets in farrowing crates spend more time in the creep area than piglets in farrowing pens, possibly because of the reduced space in crates, that the sow area is made less attractive by slatted floors and due to the horizontal bars around the sow which partly hinders physical contact with the udder (Blackshaw et al., 1994; Houbak et al., 2006; Moustsen et al., 2007). However, there are also large differences in the use of the creep area between litters even within similar housing systems (e.g. Berg et al., 2006). This large variation between litters is interesting, and it has been suggested that the sow may have an influence on piglet use of the creep area, although it is not clear exactly how and why the sow would potentially encourage this behaviour in the piglets. The idea that good maternal ability could increase the time spent in the creep area early after birth is somewhat difficult to argue. In evolutionary terms, increased communication and increased time spent together with the offspring after birth should be positive for piglet survival. Improved maternal ability should thus in fact reduce the time spent in the creep area.

2. The aim of the thesis

The overall aim of this thesis is to investigate environmental requirements and preferences in suckling piglets, and their use of the creep area.

A series of studies was conducted to address the following sub goals:

- To investigate how social and individual thermoregulatory behaviours in suckling piglets are affected by infrared temperature, bodyweight and age.
- To document the space occupied by a litter of resting piglets, and how this area is affected by infrared temperature, body weight and age.
- To investigate the preferences in newborn piglets for specific infrared temperatures and floorings.
- To investigate how two different farrowing environments and different sow breeding values for piglet survival at day 5 (ND5) affect the piglets' use of the creep area the first three days after birth.
- To examine whether a creep area designed to meet piglet preferences will increase time spent in the creep area the first two days after birth, and thereby reducing piglet mortality.

3. Methods

Several well known methods in animal science have been applied in the present thesis; still pictures were analysed in order to investigate changes in thermoregulatory behaviour and space occupation (Paper I and II). Instantaneous sampling from video recordings were used to determine preference for temperatures and floorings (Paper III), use of the creep area in pens and crates (Paper IV) and use of the creep area in pens with different creep areas (Paper V). As young piglets tend to suffer from separation anxiety when separated from the litter (e.g. Weary et al., 1999), the piglets were not separated from their litter during any of these experiments. All experimental procedures applied in this thesis were in compliance with Norwegian ethical standards for research involving live animals.

Paper I – Thermoregulatory behaviour

Ten piglets from each of sixteen litters were exposed to recommended infrared temperature conditions at 1, 2 and 3 weeks of age with a mild offset (4 °C) in infrared temperature during the first experiment and a more challenging offset (8 ºC) during the second experiment. The ten piglets were removed from their home pen and placed in one of two identical 2 m^2 experimental creep boxes (Figure 1) at 0800 h 1200 h and 1600 h in a room adjacent the farrowing unit. Digital photos were taken when all piglets had settled in the creep area, and the lying posture and huddling behaviour were analyzed. A lying posture score and a huddling score was calculated by multiplying the number of piglets in each category with a given value for each category based on different lying postures and different degrees of huddling behaviour.

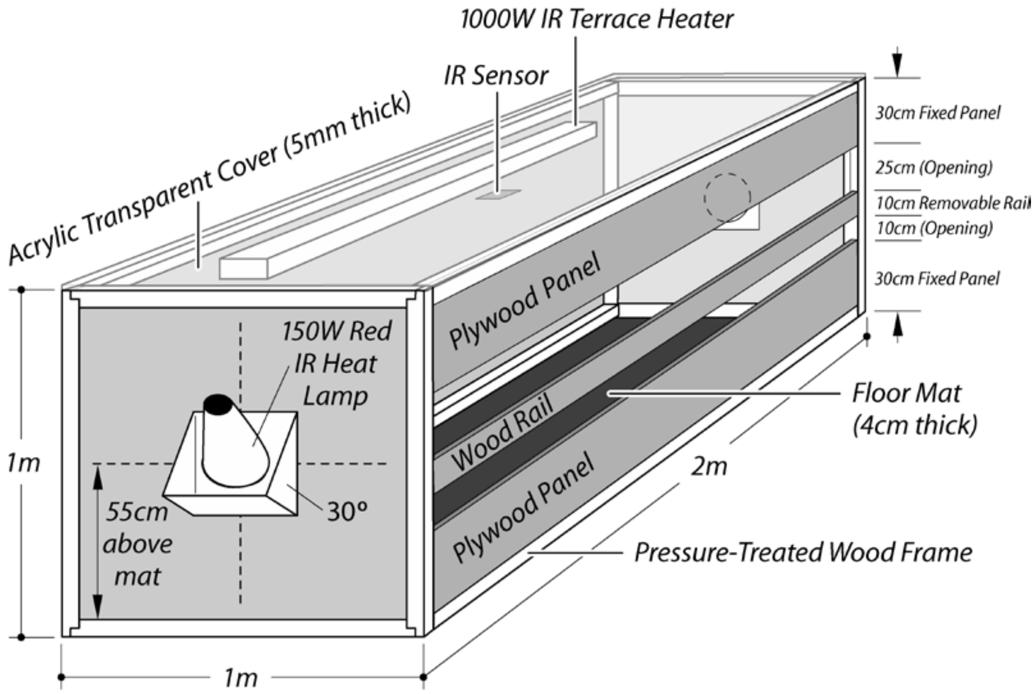

Figure 1: The experimental creep area.

The size of the experimental creep area used in Paper I and Paper II was calculated based on the idea from Petherick and Baxter (1981), where the space occupied by a piglet in sternum posture is defined as shoulder width x body length, while recumbent posture was shoulder height x body length. Thus, in a warm environment we would expect more piglets to lie in recumbent posture, while they would adopt a sternum posture in a cooler environment. Based on body measurements of 91 piglets at 7, 14 and 21 days of age (Vasdal, 2007), it was calculated that 10 three week old piglets in recumbent posture would occupy an area of 1.7 m^2. The experimental creep area of 2 m^2 was therefore large enough to document piglet thermoregulatory behaviour without spatial constraints.

Paper II – Space requirements

Ten piglets from each of sixteen litters were exposed to recommended infrared temperature conditions at 1, 2 and 3 weeks of age with a mild offset (4 °C) in infrared temperature. The ten piglets were removed from their home pen and placed in one of two identical 2 m² experimental creep boxes (Figure 1) at 0800 h 1200 h and 1600 h in a room adjacent to the farrowing unit. The lying surface on the experimental creep box floor was divided into 10 × 10 cm squares with a white spray-painted grid. Digital photos were taken when all piglets had settled in the creep area, and the space occupation was calculated as the sum of squares occupied by the ten piglets (Figure 2): 1 point for one square at least 90% covered by piglet, 1/2 point for one square 50% to 90% covered by piglet and 0 point for one square less than 50% covered by piglet.

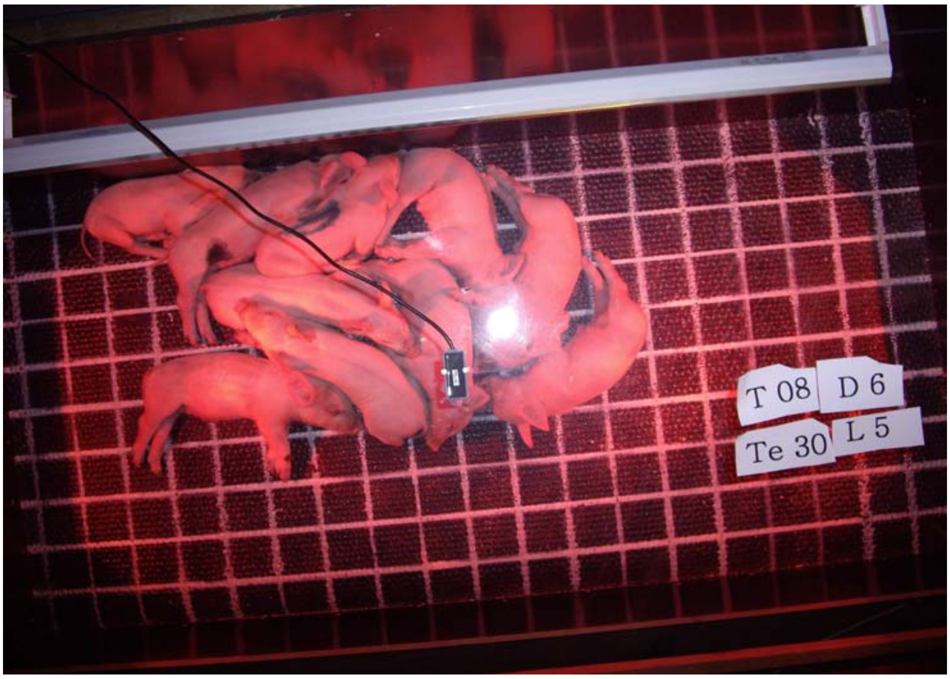

Figure 2: Piglets in the experimental creep area and the painted grid squares for space determination.

Paper III – Piglet preference

In Experiment 1, 10 piglets from each of 18 litters were distributed between three pairwise infrared temperature treatments (6 litters in each pairwise test): 26°C vs. 34°C, 26°C vs. 42°C or 34°C vs. 42°C. In Experiment 2, another 18 litters were tested in an identical setup with infrared temperatures of 30°C vs. 34°C, 30°C vs. 38°C and 34°C vs. 38°C. In Experiment 3, another 18 new litters were used to test the choice between foam mattress vs. sawdust, foam mattress vs. water mattress, and sawdust vs. water mattress. The preference test apparatus consisted of a box with three compartments: two test compartments and one neutral compartment in the middle (Figure 3). The piglets were released in the neutral compartment, and they were then allowed to explore the compartments and choose where to settle. Each litter was video recorded for one hour and the piglets' locations were scored every second minute.

Figure 3: The preference test apparatus, here seen at start of test where the piglets are located in the middle compartment.

In order to determine piglets' preference for one stimulus over another, several methods could be used, such as operant tests were the animals would be asked to work for access to a certain resource, which can also answer how important a certain stimulus is (e.g. Kirkden and Pajor, 2006; Holm et al., 2007). However, operant tests require that the animals learn to operate an operandum in order to pay a price, which would be difficult to manage in very young piglets, as in the present study. Therefore, a preference test was considered more appropriate, where time spent with each resource serves as an indicator of the preference for that resource compared to the other (e.g. Dawkins, 1977; Kirkden and Pajor, 2006). When aiming at increasing the piglets' use of the creep area the first days after birth, it was important to test the newborn piglets together as a litter, since the choice of individually tested piglets may be obscured by the effects of separation stress (e.g. Weary et al., 1999).

Paper IV – Sow breeding values in crates and pens – piglet use of the creep area

Seventy-five Yorkshire x Danish Landrace gilts housed in either pens (Figure 4) or crates (Figure 5) were video recorded for four days after farrowing. Piglet location in the pen was analysed from the video using instantaneous sampling every 10 minutes commencing 24 hours after the birth of the first piglet for a period of 72 hours.

Figure 4: The farrowing pen *Figure 5: The farrowing crate*

The experimental gilts in this study were selected from breeding sows in a herd with ongoing selection for number of piglets alive at day 5 (ND5) as a part of the selection criteria. Based on data from 10.000 litters (Su et al., 2007), the estimated breeding value for ND5 were available for all the breeding sows in the herd. Based on their breeding value, 64 of the breeding sows were divided into either high survival (HB) (EBV=0.766±0.010) or low survival (LB) (EBV=0.733±0.013). This resulted in an expected genetic difference of 0.455 surviving piglets pr litter between the HB and LB sows. From each of these breeding sows, 4 experimental gilts were chosen to our experiment, and these gilts were randomly distributed between crates and pens. Assuming the boars were randomly used for producing the experimental gilts, the expected difference between the gilts is half of the difference between the breeding sows. The experimental gilts were inseminated in their second oestrus (approximately 210 d of age) with semen from Duroc/Hampshire boars. The same boar was used to inseminate all the gilts in the experiment to reduce variability. In the present study, we used 43 HB gilts where 24 were crated and 19 were kept in pens. Of the 32 LB gilts, 19 were crated and 13 were kept in pens.

Paper V – Piglet use of the creep area and piglet mortality

Based on the preference results from Paper III, three different creep areas were designed; (1) control (CON); concrete floor in the creep area with small amount of sawdust sprinkled on the floor (2) bedding (BED); an insulated and soft bedding in the creep area (Figure 6) and (3) HUT; an insulated and soft bedding in the creep area plus an additional wall to increase the heat conserving capacity in the creep area (Figure 7). Forty-six loose-housed sows and their litters kept in individual farrowing pens were subjected to one of the three creep area treatments. The pens were video-recorded from 0-72h after birth and analysis of piglet location in the pen was conducted from 08:00 - 14:00h and from 20:00 - 02:00h on each day. A post mortem was conducted on all dead piglets in order to determine whether or not the piglets had been breathing and ingested milk.

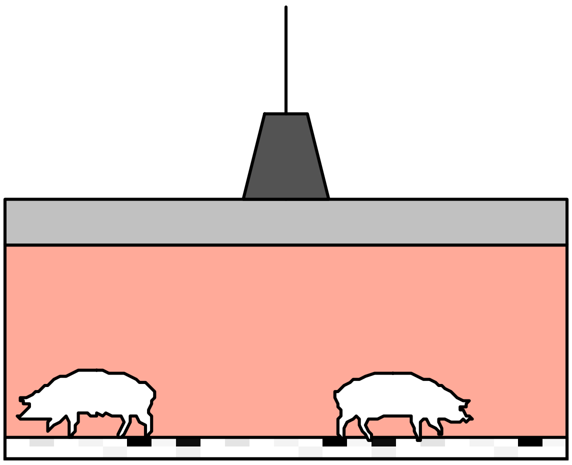

Figure 6: The 'Bedding' treatment

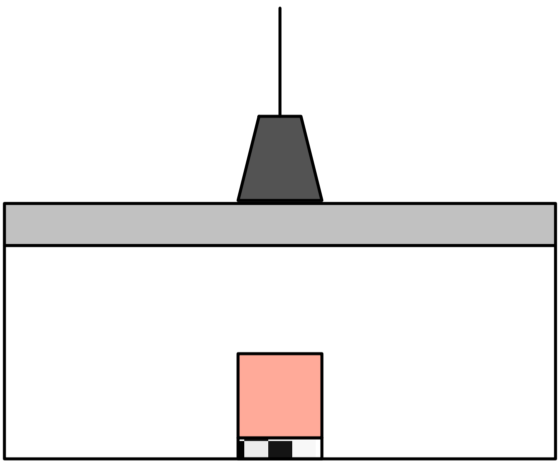

Figure 7: The 'Hut' treatment

4. Results and general discussion

4.1. Results summary

Paper I shows that as piglets grow, they get increasingly capable of using thermoregulatory behaviours like posture changes and, to a smaller extent, changes in degree of huddling to adapt to the thermal environment, but these strategies are not well developed at birth. The thermal environment thus affects the body posture and degree of huddling adopted by the piglets, which again affect the space requirements of the litter, as presented in Paper II. The fact that 24 hour old piglets prefer infrared temperatures well above their thermoneutral zone, and a thick layer of sawdust, presented in Paper III, illustrates their motivation for high temperatures and social contact, and suggest that it could be possible to attract piglets to the creep area by combining these stimuli. As maternal behaviour might influence the use of the creep area, Paper IV focused on piglet use of the creep area in crates and pens with sows of different breeding values. While piglets in crates spent more time in the creep area, there was no effect of sow breeding value on the use of the creep area. Paper V show that combining the preferred stimuli from Paper III in addition to the recommended space allowance from Paper II do not increase the use of the creep area, nor does increased time spent in the creep area reduce piglet mortality. In the following chapters, I will discuss these results and the implications of the present findings.

4.2. Thermoregulatory behaviour and effects on space requirements (Papers I and II)

The heated creep area is meant to provide the piglets with a more optimal thermal environment, and the temperature in the creep area is often measured as air temperature.

However, heat is exchanged between the piglets and their surroundings through radiation, conduction, convection and evaporation (Curtis, 1983). Infrared heat is electromagnetic radiation emitted from a hot material, like an infrared heater, and the piglets will experience infrared heat from the heat lamp although the surrounding air temperature is cooler. Hence, to measure air temperature alone will be an inadequate measure of the thermal challenge piglets are exposed to when infrared (IR) heat is supplied. As several of the studies on piglet thermoregulatory behaviour are based solely on air temperatures (Mount, 1963; Lynch, 1983; Hrupka et al., 1998), the results from the present studies provide a more precise understanding of how the thermal environment affects thermoregulatory behaviour and the subsequent effect on space use by the piglets.

When the infrared (IR) temperature was 4 ºC lower than recommended, one week old piglets tended to lie more in sternum posture in order to reduce their heat loss, however this effect was stronger when the IR temperature was 8 ºC below recommended (Paper I). Likewise, when the IR temperature was increased, the piglets adopted a recumbent posture to increase their heat loss (Figure 8). As the piglets grew older, the effects of changes in IR temperature were stronger as more piglets changed their lying posture according to the IR temperature. Thus, the piglets were able to use changes in lying posture as a thermoregulatory strategy already at one week of age, and they used postural changes increasingly as they grew older. Older, heavier pigs also adjust their lying posture according to the thermal environment and increasing the temperature results in fewer pigs lying sternum and more pigs lying recumbent (Andersen et al., 2008; Savary et al., 2009). Heavier litters spent more time in recumbent posture than lighter litters in the present study, and this is also supported by previous studies on fattening pigs (Ekkel et al., 2003; Savary et al., 2009). In addition to the reduced heat loss in larger animals due to an increased surface area to volume ratio (e.g. Seltmann et al., 2009), the thermoregulatory capacity of the pig improves with age (e.g. Herpin et al., 2002), which explains why the recumbent posture is increasing both with age and body weight.

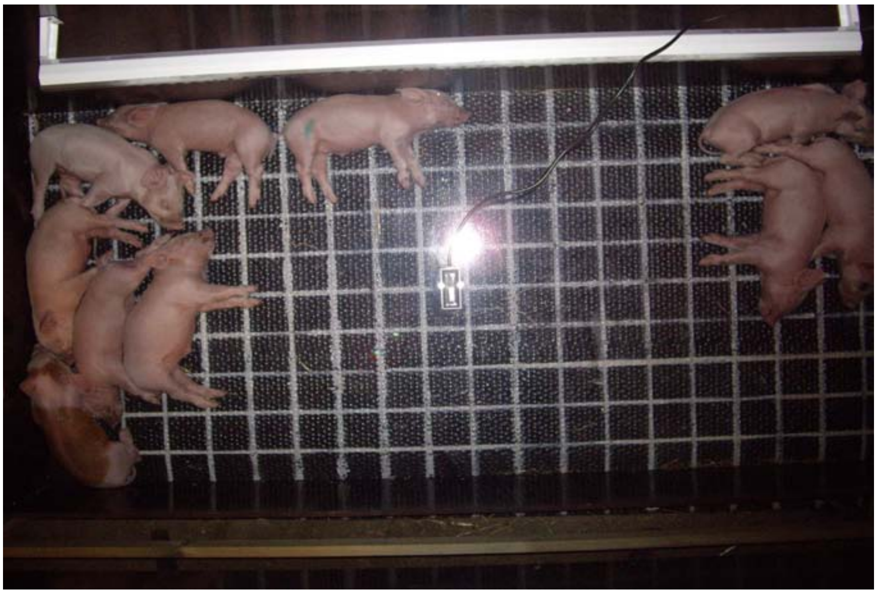

Figure 8: Piglets in recumbent posture.

Only small changes were seen in the huddling behaviour during the first two weeks after birth, both when the IR temperature changed with 4 ºC and 8 ºC. This is contrary to what is seen in older pigs that show large changes in degree of huddling when the temperature is changed (e.g. Boon, 1981; Hillmann et al., 2004; Hyunh et al., 2005). Not until the third week did we see any clear changes in huddling behaviour, and then only when the IR temperature was changed by 8 ºC. Increased litter weight was expected to decrease degree of huddling, as previous studies report that heavier pigs spend more time lying without physical contact to their pen mates (Boon, 1981; Hillmann et al., 2004), but there were no effects of weight on the degree of huddling in the present study.

Posture changes appear to be used to a larger extent than changes in degree of huddling the first two weeks after birth. More than half of the piglets were huddling with three or more littermates during the warmest temperatures, even at three weeks of age when their heat producing ability is thought to be well developed (e.g. Herpin et al., 2002). The experimental creep area was large enough for the piglets to avoid body contact if they wanted, but the motivation to remain close to littermates may be strongly rooted in survival strategies. In addition to the adaptive functions of remaining close together with littermates, the possibility for the litter to spread out within the nest may be spatially limited (Mayer et al., 2002), thus reduced huddling is not used to a large extent as a thermoregulatory strategy at this early age. The fact that the piglets maintained a high degree of huddling despite high infrared temperatures suggests that individual resting position, rather than the degree of huddling, should be used as an indicator of thermal comfort in young piglets.

As IR temperature affects the lying posture and degree of huddling (Paper I), it will also affect the space occupied by a litter, since piglets that spread out in recumbent posture uses a larger area than piglets huddling in sternum posture (e.g. Boon, 1981; Ekkel et al., 2003). In the present study (Paper II), a litter of 10 resting piglets, at recommended temperature, occupied 0.6 m^2, 0.7 m^2 and 0.9 m^2, at one, two and three weeks of age, respectively. However, a 4 ºC change from the recommended IR temperature had a significant effect on total space occupied during all three weeks due to the changes in lying behaviour. As expected, at 4°C above recommended temperature, the piglets occupied 12% more space than observed at recommended temperatures. Likewise, the piglets occupied 9% less space when exposed to 4°C below recommended temperature.

Most litters today are larger than 10 piglets, and it is vital to construct a creep area large enough to accommodate the whole litter at once, as they prefer to lie close to each other (Hrupka et al., 2000a), and piglets outside the heated creep may be in more risk of hypothermia and crushing. Although the space requirement is reduced in a cooler environment, a creep area with temperatures well below the piglets' thermal requirements will not attract piglets (Schormann and Hoy, 2006), nor provide the required temperature, and should not be considered as a solution to reduce the space requirement.

In summary, suckling piglets are able to change their individual resting position to adapt to their thermal environment, and change the degree of huddling to a smaller extent. However, posture changes are developed earlier and seem to be more sensitive to changes in IR temperature. Increased infrared temperature in the creep area, increased age and body weight all affect the resting position of the litter, and will therefore also affect how much space the piglets occupy. A creep area that must accommodate at least 14 piglets at three weeks of age at recommended temperatures should be a minimum of 1.26 m^2.

4.3. Environmental preference in neonatal piglets (Paper III)

When given the choice between temperatures of 26 ºC, 34 ºC or 42 ºC, the piglets showed a clear preference for the highest temperature, which was rather surprising as this is 8 ºC above their thermoneutral zone. However, Hrupka et al. (2000b) found that single piglets prefer temperatures as high as 48 ºC; and our results show that high temperatures are also attractive for a litter of piglets. As the compartments in the test apparatus was heated by heat lamps, the higher temperature compartments would have a higher illumination level. Previous studies documented that piglets are attracted to dim or dark areas (Parfet and Gonyou, 1991). However, since the piglets preferred high temperatures despite the higher illumination levels suggests that the preference for high temperatures exceeds their preference for darkness.

When the piglets were given the choice between 30 ºC, 34 ºC or 38 ºC, they showed no clear preference for any of these temperatures. This might be due to the piglets being unable to differentiate between these temperatures or that they had no preference for temperatures in the range tested. Under natural circumstances, piglets do not need to be fine tuned to specific temperatures; instead they would be attracted to the warmest and softest surface in their surroundings, i.e. the sow's udder (e.g. Fiala and Hurnik, 1983).

Consistent with the strong motivation in piglets for being close to their litter mates, we observed that when the first piglets settled in one of the compartments, the other piglets soon followed, settled next to them, and remained there throughout the test period. The fact that piglets preferred to stay together with their littermates fits well with the results in Paper I; piglets prefer to lie close together despite having enough room to spread out even at temperatures above 40 ºC. The results from Paper III thus confirms earlier findings that young piglets are able to choose their location based on preferences for thermal environment and the presence of litter mates (e.g. Titterington and Fraser, 1975; Farmer and Christison, 1982; Welch and Baxter, 1986; Hrupka et al., 2000a).

It was observed that some of the piglets that chose the 42 ºC compartment rested with parts of their body outside the heated compartment, possibly indicating that the temperature was above their thermal comfort, especially when the whole litter was huddling together. This may be interpreted as the motivation for social contact was overriding the motivation for thermal comfort, which is also found by others (e.g. Hrupka et al., 2000b). Considering that piglets chose 42 ºC, it can be discussed whether the creep area in the pen should be kept at such a high temperature to stimulate piglets of this age to enter them, or rather heating it to a temperature that is healthy for the piglets. Remaining in 42 ºC for a longer period of time may be negative for the piglets, as temperatures above their thermoneutral zone may lead to a reduction in metabolic rate due to heat stress (e.g. Curtis, 1983).

When the piglets were given the choice between a thick layer of sawdust, a foam mattress and a warm water mattress, the piglets clearly preferred sawdust to the foam mattress, but showed no preference between sawdust and water mattress, or between foam mattress and water mattress. The water mattress was expected to be preferred, as previous studies have found a clear preference for a warm water bed over other types of floorings in crates (Ziron and Hoy, 2003). Sawdust may be attractive due to its insulating qualities and the fact that it is soft and easy to manipulate. The preference for sawdust might also have been due to the familiarity of this substrate from their home pens, with its positive associations to maternal smells (e.g. Morrow-Tesch and McGlone, 1990), although a small amount of sawdust was sprinkled on the other two beddings in order to reduce this effect.

In summary, these experiments show that day-old piglets have the ability to assess their environment, and that they have clear preferences for 42ºC and a thick layer of sawdust. It appears that their thermal preference is higher than their thermoneutral zone, at least for a short period of time away from their home pen. The fact that several piglets were observed lying partly outside the heated area, suggest that the motivation for social contact might be stronger than the motivation for thermal comfort.

4.4. Piglet use of the creep area (Papers IV and V)

Piglets had a clear preference for high temperatures and a thick layer of sawdust in Paper III, so this was added to the creep areas in an attempt to make an attractive creep area in the pen. At the same time, I wanted to investigate the relationship between time spent in the creep area early after birth and piglet mortality. A reduced mortality due to increased use of the creep area has not to my knowledge been documented. In fact, Berg et al. (2006) found no relationship between time spent in the creep area and piglet mortality.

Piglets in pens spent less time in the creep area and more time resting in contact with the sow compared to piglets in crates, as expected. Blackshaw et al. (1994) reported similar results and this difference may be due to the differences in physical layout between the environments. The creep areas in the crates and pens were both equipped with heat lamp and similar amount of straw, making the quality of the creep area equal. However, an important difference between the two environments was that in crates, 50 % of the floor surface was slatted, whereas in the pen only 25 % was slatted. The creep area in the crate may thus have been perceived as more attractive than the sow area, since slatted floors result in skin abrasions and swollen limbs and claws in piglets (e.g. Lewis et al., 2005; KilBride et al., 2009). Also, the horizontal bars next to the sow may have interfered with the piglets' opportunity to lie close to the sow's udder where heat is provided (Fraser and Thompson, 1986; Thompson and Fraser, 1986).

Maternal behaviour will be affected by the environment in which they are housed. Crated sows show increased activity of the HPA axis prior to farrowing (e.g. Lawrence et al., 1994; Jarvis et al., 1997), perform more stereotypies (e.g. Damm et al., 2003; Hotzel et al., 2005) and have more frequent posture changes (Cronin et al., 1994) compared to sows in pens. In addition, the increased ability of the sow to perform nest building behaviour prior to farrowing, and to move around and interact with her piglets in the pen have positive effects on maternal behaviour (Cronin and Smith, 1992; Cronin et al., 1996; Damm et al., 2003). These factors, together with an increased time spent nursing in the pen (e.g. Arey and Sancha, 1996) have likely increased the attractiveness of the sow, and thus increased the time spent near the sow in the pen. A third factor that may influence the use of the creep area is the distance between the creep area and the most commonly used resting place for the sow in the pen (e.g. Zhang and Xin, 2001). A shorter distance from the sow to the creep area in crates may therefore have increased the use of the creep area in crates.

Despite some promising selection results on maternal behaviour in other studies (Chiang et al., 2002a; Vangen et al., 2005), there were no effects of the sows breeding value on piglet use of the creep area in Paper IV. In addition, there was no difference between sow breeding values with regards to piglet mortality (results on mortality is reported in Pedersen et al., submitted). The expected genetic difference between the sows with high and low breeding value in the experiment would be around 0.225 piglets, which theoretically results in 22.5 piglets extra in a herd of 100 sows. However, the lack of differences in mortality between the different breeding values may be due to low heritabilities of the trait piglets alive at day 5 (ND5) (Su et al., 2007), resulting in a low accuracy of the estimated breeding values. This can result in a large genetic variation within different breeding values, thus reducing any potential differences. A difference between the breeding values in the use of the creep area would only occur if the selection had a direct effect on the sow's maternal behaviour, and then only if maternal behaviour had an effect on the use of the creep area.

Based on the clear preference for high temperatures and sawdust (Paper III), the hut treatment was expected to be attractive to the piglets, but the hut was the least used of the three different creep areas in Paper V. One could argue that this might be due to a smaller entrance into the hut, but Moustsen and Jensen (2007) found no difference in the use of the creep area between creep areas with a small (60 cm) and large (110 cm) entrance. None of the three creep areas in the present study were able to attract the piglets away from the sow to a larger extent than seen in other studies of loose housed sows (Berg et al., 2006; Moustsen and Jensen, 2007; Paper IV). This is likely due to the strong motivation in piglets to remain close to the sow and littermates the two days after birth, regardless of the presence of a heated creep area (e.g. Hrupka et al., 1998; Andersen et al., 2007). As newborn piglets are attracted to several of the stimuli provided by the sow; soft and warm surfaces (Welch and Baxter, 1986) in addition to maternal odours and vocalizations (e.g. Parfet and Gonyou, 1991), it appears rather difficult to attract newborn piglets away from the sow.

It is uncertain exactly how much contact between the sow and piglet outside the time of nursing is optimal for piglet survival, or if breeding for improved piglet survival should increase or decrease the use of the creep area. From a biological point of view, increased time spent with the sow should increase piglet survival, as long as the sow is attentive and protective. Also, the sow chooses to remain close to her piglets during the first two days after birth despite having the opportunity to leave (e.g. Stangel and Jensen, 1991; Pajor et al., 2000). Thus, it can be argued that most individual pens, which assume that newborn piglets will seek away from the sow, and into a heated creep area, are designed in a non-functional way.

In accordance with previous findings (e.g. Berg et al., 2006), there were large differences between litters, also within the same treatment, with regards to how much time the piglets spent in the creep area in Paper V. However, there was no relationship between time spent in the creep area and piglet mortality. In fact, litters that spent more than 70 % of their time in the creep area had similar mortality as litters in the same treatment spending less than 4 % of their time there. Previous studies (e.g. Berg et al., 2006) have suggested that the differences in use of the creep area might also be due to differences in maternal behaviour, but it is difficult to argue how improved maternal behaviour would increase the use of the creep area. As discussed earlier, seen from the piglets' perspective, increased time spent near the udder should rather increase piglet survival. Contrary to previous studies (e.g. Weary et al., 1996), there was no relationship between time spent resting near the sow and piglet mortality in the present study, which further highlight the fact that increased time spent with the sow may be positive for piglet survival.

Litter size had no clear effect on mortality in Paper V, contrary to previous findings (e.g. Pedersen et al., 2006; Weber et al., 2009). Although large litter sizes are known to increase mortality, the potential negative effects of large litter sizes might have been camouflaged by the cross fostering, as the sows never had more piglets than functional teats. A majority of the piglets that died had no milk in the stomach, suggesting that starvation was a major cause or a predisposing factor for the mortality. Other individual piglet characteristics, like birthweight, body temperature, vigour at birth and latency to first suckle (Noblet and Le Dividich, 1981; Tuchscerer et al., 2000; Pedersen et al., 2008; Baxter et al., 2008; Vasdal et al., in press) may explain most of the mortality, however these variables were not documented in the present study.

If increased use of the creep area is positive for piglet survival, differences in mortality should be expected between litters with high and low use of creep area. However, there were no differences in mortality between the farrowing environments in Paper IV (mortality records in Pedersen et al., submitted) despite large differences in use of the creep area, nor was there any relationship between time spent in the creep area and piglet mortality in Paper

V. The results from these papers thus suggest that the creep area may be less important for piglet survival than previously thought. With regards to reducing piglet mortality, other designs of the farrowing pens that fit the biology of the sow and piglets should be developed.

In summary, improving the thermal comfort and softness in the creep area did not increase the use of the creep area within day 3 post partum, nor did increased time spent in the creep area reduce piglet mortality in loose housed sows. Piglets in crates spend more time in the creep area early after birth; but there were no difference in the use of the creep area between the two breeding lines for piglet survival. The results from Paper IV and Paper V thus suggest that the creep area may be less important for piglet survival than previously thought.

4.5. Concluding remarks

These studies have shown that young piglets are able to adjust their individual thermoregulation in response to the thermal environment and they have clear preferences for 42 ºC and sawdust. However, the sow will always be preferred over the creep area, due to the strong motivation in piglets to lie near the sow where they gain heat and food. As time spent in the creep area appears to have little impact on piglet survival, more focus must be put on other factors related to the pen design. To improve maternal behaviour is extremely important, especially when the sow is kept loose. Although not the focus of the present thesis, the farmers’ management around farrowing also plays a major role in the survival rate (e.g. Andersen et al., 2009; Vasdal et al., in press), and may be the most crucial factor when litter size is exceeding the sows capacity.

4.6. Practical implications

The fact that the piglets stayed close together despite high infrared temperatures has direct implications for practical use, as the resting pattern of pigs is thought to be a reliable response to the thermal comfort. Rather than looking at degree of huddling, the individual resting position of the piglets is a more reliable indicator of the thermal comfort of a suckling piglet. A litter of 10 resting piglets, at recommended temperature, occupied 0.6 m^2, 0.7 m^2 and 0.9 m^2, at one, two and three weeks of age, respectively. If the creep area should be able to accommodate 14 piglets at three weeks of age at recommended temperature, the creep area must be at least 1.26 m^2. Increasing the quality of the creep area by optimizing the size, temperature and bedding will not increase the use of the creep area, nor does increased use of the creep area reduce piglet mortality when sows are kept loose. Despite the lack of effect on mortality, the creep area is used more by the piglets from day 3, and many farmers consider the creep area important for separating the sow and piglets, and for closing the piglets inside during practical routines, and this must also be taken into consideration when designing more optimal pen systems.

4.7. Suggestions for further research

Based on the findings in this thesis, it would be interesting to investigate the effect of housing sows in farrowing pens without a creep area, but with a separate nest area. This would provide the sow with an opportunity to regulate the contact with her piglets, and to feed, drink and defecate away from the nest area. As more countries are changing to loose housing systems for lactating sows, it is important to develop a farrowing pen design that stimulates the sow to do most of the job herself, which may also help reduce piglet mortality. However, regardless of how optimal the pen may be, with the increasing litter sizes seen today, farmers' management around farrowing is more important than ever, and will always be on of the most efficient ways of reducing piglet mortality in the short term.

Finally, more focus must be put on the negative side effects of the ongoing breeding program with too much emphasize on number of liveborn, as this selection has negative effects on several sow and piglet characteristics which plays an important part in piglet survival and sow longevity. Another important area to focus on is the feeding of gestating and lactating sows, as litter size and milk production has increased substantially, while sow feed intake is often insufficient to meet their nutritional requirements. This can have negative effects on their lactation performance, the weaning to estrus interval and their subsequent performance in the next litter (e.g. O'Dowd et al., 1997; Eissen et al., 2000; Sinclair et al., 2001; Prunier et al., 2010).

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Acknowledgments

The studies presented in this thesis were part of the project ‘Farrowing environment and the impact on piglet survival and sow-piglet interactions’. Financial support was given by the Research Council of Norway. ‘Takk for det!’

First of all, I want to thank my main supervisor, the wonderful, sparkling, challenging and warm Inger Lise Andersen, for so many memorable experiences during these years; via dancing in Dublin, to long crazy nights in the pig farm and exclusive dining in Cambridge. I would also like to thank you for your invaluable help on everything from statistic models to behavioural theories, for your patient explanations, your constructive comments on an infinite number of manuscripts, for our interesting discussions and for always holding your open door for me. Hopefully, you won’t have to write ‘GPP’ in any more of my manuscripts!

Gratitude is also due to my other supervisors, Knut Bøe, for all your ideas and important comments on experimental set ups, constructive feedback on my many manuscripts and for sharing all your experience with me. I will always appreciate your opinions, and your ability to keep the scientific talk at “Cake-Friday” to a minimum. Thank you Lene Juul Pedersen for a great Danish experience in Foulum when I was just a young PhD fledgling, and for all your help and comments on the manuscripts. Thank you Donald Broom, for an amazing and unforgettable stay in Cambridge, for your valuable comments on manuscripts, and for taking the time to reply to my many emails with warm and helpful answers. Thank you Greg Cronin for patiently and enthusiastically answering all my questions regarding the preference experiment, and for taking good care of me at the ISAE in Cairns, and for taking good care of my supervisors and their family during their stay in Australia.

A big thank you to the excellent girls who have done their master work as part of my project; Ingrid Møgedal, Marit Glærum and Ingrid Østensen, it was a pleasure having you onboard, and you have all made this experience great for me. Thank you also Misha, Bara and Gudrun for great team work in the pig barn and around the computer afterwards.

Thank you Bjørn Gevelt, for letting us observe your sows and piglets, for sharing your knowledge on pig management, and for sharing your wine in the late hours of the night when we were exhausted after a long shift with your wonderful pigs.

Big thanks are also due to the staff at the Pig Research Unit at UMB; Linda, Trygve and Birgit for always helping us with problems big and small, and for taking good care of the research piggies.

Thank you my inspiring colleagues in the Ethology group, I can learn and laugh so much just by having my cup of tea with you guys. I appreciate all our interesting lunch discussions, although some of the topics we discuss are not suitable for printing! A special thanks to my office mates, Grete and Natasa, for keeping up with all my questions and exclamations during these years, and for our funny wine evenings. I know I would be so unhappy in a single office!

Thank you, mamma and pappa, for always supporting me in every way and being there for me, and for taking good care of Phoebe when I vacate the country from time to time.

Finally, thanks to my wonderful girls; Marit, Flesjø, Haugen, Olsen, Kristin, Karoline, Heidi, Guro, Lene, Silje and Hanne Guro for being the pillars in my life. Thank you for always being there for me in your own special way, and for being the amazing women you are. You will all be with me for life.

And of course, thank you Phoebe, for being a shining, happy, patient, funny, enriching gold nugget every single day. You truly are an angel with a wagging tail. And to those not mentioned, you are definitely not forgotten!

‘Du skal ikke tåle så inderlig vel, den urett som ikke rammer deg selv’

-Arnulf Øverland

Animal (2009), **3:10**, pp 1449–1454 © The Animal Consortium 2009
doi:10.1017/S1751731109990309

Effect of infrared temperature on thermoregulatory behaviour in suckling piglets

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(Received 3 October 2008; Accepted 14 May 2009; First published online 8 June 2009)

The objective of this study was to investigate the effect of infrared (IR) temperature on thermoregulatory behaviour in suckling piglets in the first 3 weeks after farrowing. A total of 10 piglets from each of the 16 litters were exposed to recommended IR temperature conditions at 1, 2 and 3 weeks of age, with a mild offset (4°C) in IR temperature during the first experiment and a more challenging offset (8°C) during the second experiment. Digital photos were taken when all piglets had settled in the creep area, and the lying posture and huddling behaviour were analysed. A lying posture score and a huddling score was calculated by multiplying the number of piglets in each category with a given value for each category, based on different lying postures and different degrees of huddling behaviour. With a 4°C change in IR temperature, the piglets tended to alter their lying posture, while an 8°C change had a significant effect on lying posture ($P < 0.01$*). A change in IR temperature of 4°C had no effect on the degree of huddling. The huddling score decreased significantly with 8°C change in IR temperature (*$P < 0.05$*). Postural changes, rather than changes in degree of huddling were the preferred thermoregulatory strategy for suckling piglets.*

Keywords: huddling, infrared temperature, suckling piglets, swine, thermoregulatory behaviour

Implications

Suckling piglets are capable of using thermoregulatory behaviours, like posture changes and huddling, to adapt to the thermal environment; however, these strategies are not well developed at 1 week of age. The tendency for piglets to lie close together despite high infrared temperatures has implications for practical use as the resting pattern of pigs is thought to be a reliable response to the thermal comfort; however, this might not be a correct conclusion for young piglets.

Introduction

Piglet mortality is a source of major loss to the swine industry worldwide, with a death rate of 12% to 13% of live-born in the UK (Edwards, 2002) and 14% to 15% in Norway (Norsvin, 2005). Although hypothermia is rarely recorded as cause of death, it might often be the primary cause of starvation and crushing (reviewed by Edwards (2002)), as hypothermia renders the piglet less viable and in more danger of starvation and crushing (English, 1993). Heat is exchanged by animal and environment at all times via radiation, convection, conduction and evaporation (Curtis, 1983). This heat exchange is especially critical for piglets directly after birth, as piglets suffer a 15°C to 20°C drop in ambient temperature (Herpin *et al*., 2002). This can result in a 2°C drop in body temperature, and the piglet needs up to 48 h to recover to normal body temperature (Berthon *et al*., 1993). In order to increase heat production, piglets depend on muscular shivering thermogenesis, which demands valuable energy (Berthon *et al*., 1994). To reduce heat loss, on the other hand, is far less energy demanding. One effective strategy to reduce heat loss is by social thermoregulation, as a huddling litter of newborn piglets can reduce their lower critical temperature, which is ideally 34°C, to 25°C to 30°C (Close, 1992). Huddling behaviour has been seen to reduce with age as the piglets increase their live weight (Boon, 1981). A second strategy for the piglet to reduce heat loss is to adjust its postural position; conductive heat loss is reduced by the adoption of a sternum posture from a recumbent posture (Mount, 1967). As the piglets grow heavier, the recumbent position is increasingly used as the sleeping position, with some pigs spending over 80% of the night and day in this position in a thermoneutral temperature (Ekkel *et al*., 2003); however, little is known about the preferred resting position for suckling piglets.

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Room temperature in the farrowing unit is normally kept at the sows' thermal comfort zone, around 20°C (Svendsen and Svendsen, 1997). In order to create an optimal thermal environment for the piglets, heat sources are added to the creep area, either as floor heating or more commonly as an infrared (IR) heater. IR heat is preferred by piglets the first 2 days after birth (Zhang and Xin, 2001). IR heat is more effective than conductive floor heat, both for drying off birth fluid and also to recover body temperature which can take up to 48 h (Berthon *et al*., 1993). Effective environmental temperature theoretically expresses the total effect of a particular environment on an animal's heat balance. Hence, when supplying radiant heat, the air temperature alone is an insufficient measure of the thermal challenge in that environment (Curtis, 1983). However, several of the studies on piglet thermoregulatory behaviour are based solely on air temperatures (e.g. Mount, 1963; Lynch, 1983; Hrupka *et al*., 1998).

The aim of this study was to examine the effect of IR temperature on thermoregulatory behaviour in suckling piglets in the first 3 weeks after farrowing. It is hypothesized that the piglets will huddle closer together and adopt a sternum lying posture as IR temperature decreases. Further, it is hypothesized that the use of these thermoregulatory strategies will increase with the age of the piglets.

Material and methods

Experimental design

Suckling piglets were exposed to recommended IR temperature conditions at 1, 2 and 3 weeks of age, with a mild offset of 4°C above and below the recommended temperature during the first experiment and a more challenging offset of 8°C above and below the recommended temperature during the second experiment (Table 1). Recommended IR temperatures were based on the IR heat system manufacturer (Veng System, Roslev, Denmark) for conditions commonly seen in practice. Both experiments were conducted at the Pig Research unit at the Norwegian University of Life Sciences. In each experiment, eight litters with 12 to 15 healthy crossbred piglets (Duroc boars with Landrace × Yorkshire sows), born within a 24-h period, were randomly allotted to the experiment.

The litters were exposed to the experimental conditions at week 1 (6, 7 and 8 days of age), week 2 (13, 14 and 15 days of age) and week 3 (20, 21 and 22 days of age). Within each weekly treatment, half of the litters (group 1) were exposed to IR temperatures 4°C or 8°C lower than recommended on the first day, recommended temperature on the second day and to IR temperatures 4°C or 8°C higher than recommended on the third day (Table 1). The other half of the litters (group 2) were exposed to IR temperatures higher than recommended on the first day, recommended temperature on the second day and lower than recommended on the third day.

Experimental procedure

During each experimental day, 10 piglets from each of the two litters were gently removed from their farrowing pen and placed in one of the two identical experimental creep boxes (Figure 1) at 0800, 1200 and 1600 h at IR temperatures according to the experimental design (Table 1). The experimental creep boxes were in a different room than the farrowing unit, and the piglets were not able to hear sow grunts, which could have affected their behaviour. After all the piglets had settled and were lying steadily (typically around 15 min), a digital photo was taken before the piglets were returned to their respective farrowing pens. At 1 week of age, the nursing pattern is normally once every hour, and this interval increases with age (e.g. Bøe, 1991). As the litters were away from the sow for a maximum of 15 to 20 min, time since last nursing would not likely affect the results. This procedure was then repeated for the remaining litters. The experimental piglets were individually weighed on days 7, 14 and 21 (DIGI scale, 100 g resolution; DIGI Europe, Suffolk, UK).

Experimental creep box

Two creep boxes were constructed with materials and dimensions shown in Figure 1. The floor was covered with a dairy-cow mattress assembly with a black, textured rubber (5 mm thick) top layer over a 5 cm thick foam blanket (cow mattress; DeLaval, Tumba, Sweden). The floor area was determined to be more than adequate for 10 large piglets in recumbent position at 21 days of age with no space sharing (Wheeler *et al*., 2008). Heat from the two 150 W heat lamps was regulated by an IR temperature controller (Model VE122S IR Controller; Veng Systems, Roslev, Denmark), using an IR temperature sensor (Model VE181-50 speed\light sensor; Veng Systems) mounted in the acrylic ceiling panel. These two 150 W lamps provided all the heat during evaluation of temperatures 17°C to 25°C, but were supplemented with a larger IR heater for higher temperatures (1000 W; Infra

Table 1 *Temperature design for experiment 1 and experiment 2*

		Week 1			Week 2			Week 3		
Experience	Piglet age (days)	6 days	7 days	8 days	13 days	14 days	15 days	20 days	21 days	22 days
1	Group 1 (°C)	38	34[a]	30	31	27[a]	23	29	25[a]	21
1	Group 2 (°C)	30	34[a]	38	23	27[a]	31	21	25[a]	29
2	Group 1 (°C)	42	34[a]	26	19	27[a]	35	33	25[a]	33
2	Group 2 (°C)	26	34[a]	42	35	27[a]	19	17	25[a]	17

[a]Recommended temperature for age.

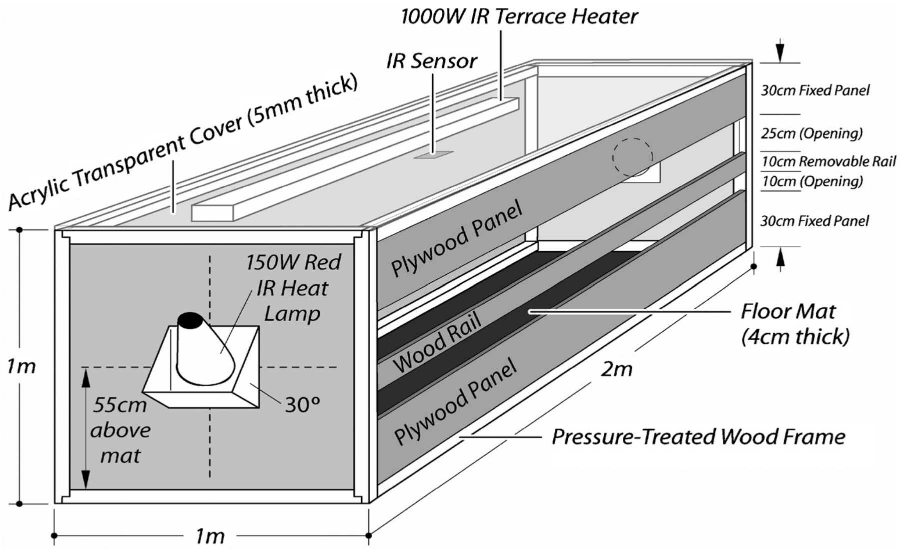

Figure 1 Experimental creep area.

Värmare, Stockholm, Sweden). A dry-bulb air temperature sensor (thermistor; Veng Systems) was positioned close to piglet height, 55 cm from floor, in the corner of the experimental box where it was not impacted by IR radiation. The IR temperature is higher than the air temperature because it includes the effect of the radiant heat supplied by the IR heaters, and thus it is an important factor in the effective environmental temperature experienced by the piglets. The difference between air temperature and IR temperature (ΔT) was 2°C in the lower experimental temperatures, and increased to 8°C during the highest experimental temperatures. More details on creep box construction and IR lamp operation can be found in Wheeler *et al*. (2008).

Behaviour observations

At 15 min after all the piglets were lying steadily, a digital photo was taken using a digital camera (Pentax Optio A10, Pentax Europe GmbH/Germany) mounted 1.8 m above the centre of the creep box. Each piglet was scored for lying posture and degree of huddling, using the following ethogram:

Lying posture:

1. Fully recumbent: Whole side of body in contact with floor, all legs to one side
2. Partly recumbent: More than half but not the whole the side of body in contact with floor, one or no legs under body
3. Partly sternum: Less than half the side of body in contact with the floor, legs partly under body
4. Fully sternum: All four legs under the body, with belly in contact with the floor

Huddling:

Low degree of huddling (no body contact):

1. More than 10 cm away from nearest piglet, without any body contact
2. Less than 10 cm away from nearest piglet, but without any body contact

Medium degree of huddling (body contact):

3. Body contact with one other piglet
4. Body contact with two piglets
5. Body contact with three or more piglets

High degree of huddling (on top of other piglets):

6. Less than 50% of piglet body on top of one or more piglets
7. More than 50% of piglet body but not whole body on top of one or more piglets
8. Whole piglet body on top of one or more piglets

A lying posture score (PS) and a huddling score (HS) was calculated by multiplying the number of piglets in each category with the above score for each category based on different lying postures and different degrees of huddling behaviour. A high PS represents a high degree of piglets lying sternum, and a high HS represents a high degree of huddling behaviour.

$$\text{Posture score} = P1 \times n1 + P2 \times n2 + P3 \times n3 + P4 \times n4,$$

(P1, P2, P3 and P4 = value for posture category, n1 to n10 = number of piglets in a posture category. Range for score from 10 to 40).

$$\text{Huddling score} = H1 \times n1 + H2 \times n2 + H3 \times n3 + H4 \times n4 + H5 \times n5 + H6 \times n6 + H7 \times n7 + H8 \times n8,$$

(H1 to H8 = value for huddling category, n1 to n10 = number of piglets in the various categories. Range for score from 10 to 80).

Table 2 *Average huddling score in the two set of experiments (means ± s.e.)*

Experience	Treatment period	IR-temperature			Interactions week * IR temperature	
		Low	Recommended	High	$F_{4, 10}$	*P*-value
1	Week 1	49.9 ± 2.1	46.2 ± 2.1	48.5 ± 2.2	0.53	ns
	Week 2	57.5 ± 3.3	57.9 ± 2.9	55.4 ± 2.1		
	Week 3	61.7 ± 2.5	59.9 ± 2.7	55.6 ± 3.3		
2	Week 1	69.5 ± 2.5	73.0 ± 2.7	66.3 ± 1.6	3.65	<0.05
	Week 2	72.6 ± 2.3	69.0 ± 1.5	62.4 ± 2.8		
	Week 3	75.2 ± 3.0	71.7 ± 1.5	57.3 ± 2.3		

IR = infrared.

Statistical analysis
The observations were analysed to determine the effect of IR temperature on thermoregulatory behaviour, and each experiment was analysed separately. We employed a general mixed linear model, using the Mixed procedure in SAS version 9.1 (Hatcher and Stephanski, 1994). The model was:

$$\text{Score} = \text{IR temp} + \text{group} + \text{litter weight} + \text{week} + \text{litter (group)} + \text{day} * \text{week} * \text{litter} * \text{group} + e, \quad \text{(model 1)},$$

where 'score' is the HS (continuous, range 36 to 107) or lying PS (continuous, range 11 to 40), 'IR temp' is effect of IR temperature (class, high, recommended or low), 'group' (class) is effect of starting with low or high temperature, 'litter weight' is effect of mean litter weight, (covariate, range 2.5 to 10.5 kg), 'week' is effect of week (1, 2 or 3) and 'litter' is effect of litter (class, 1 to 8). Finally, 'day * week * litter * group' is the random effect of the interaction between day (class, 1, 2 or 3), week, litter and group, and 'e' is the residual variation not accounted for by the model. The random effect of day * week * litter * group was included to obtain appropriately conservative tests. However, the d.f. did not change to an appropriately low number when including random effects. We thus chose to assign denominator d.f. manually to further ensure conservative tests. The following denominator d.f. were assigned for testing the fixed effects (in the order of the above model): 20, 6, 10, 20, 10 and 10.

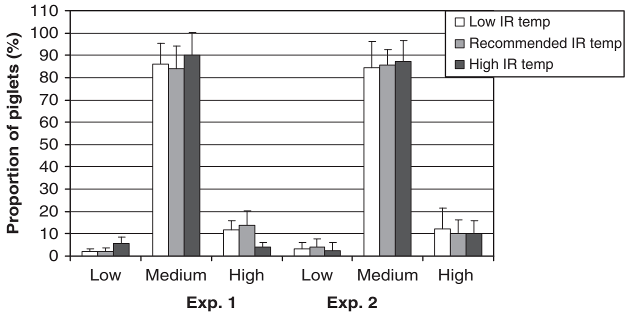

Figure 2 Proportion of piglets (%) in different degrees of huddling during week 1.

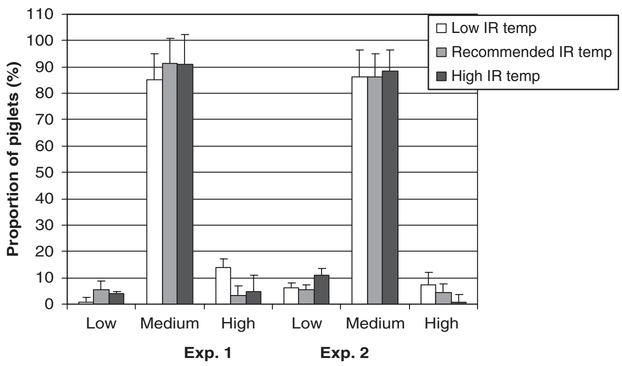

Figure 3 Proportion of piglets (%) in different degrees of huddling during week 2.

Results

Huddling behaviour
There was a significant interaction between IR temperature and week on HS in experiment 2 ($F_{4,10} = 3.65$, $P < 0.05$), but not in experiment 1 (Table 2). In experiment 2, HS increased in week 1 when IR temperature was decreased; however, there were no changes in HS with changes in IR temperature in experiment 1 (Table 2). Most piglets adopted a medium degree of huddling in both experiments; more than 80% of the piglets were lying in body contact with one or more piglets despite a 16°C change in IR temperature (Figure 2). Less than 10% of the piglets were lying without body contact regardless of IR temperature. The proportion of piglets with a high degree of huddling increased from 5% to 12% with decreased IR temperature in experiment 1, and from 10% to 12% in experiment 2.

There was a further increase in HS when IR temperature was decreased in week 2 and this effect was even stronger in week 3 in experiment 2 (Table 2). HS tended to increase with decreasing temperatures in experiment 1 as well; however, the effects were not significant. Most piglets still maintained a medium degree of huddling in both experiments; over 80% of the piglets were lying in body contact with one or more piglets during all IR temperatures in week 2 and 3 (Figures 3 and 4). The proportion of piglets lying in body contact increased from 85% to 91%, and from 86% to

90% in week 2 and 3, respectively, when IR temperature was decreased (Figures 3 and 4). Less than 10% of the piglets were lying without body contact regardless of IR temperature. The proportion of piglets lying on top of other piglets (high degree of huddling) increased when IR temperature was decreased in week 2 (Figure 3), but this effect was not present in week 3 (Figure 4). Mean litter weight had no effect on HS. There was no effect of the time of day on huddling behaviour.

Lying posture
There was a significant interaction between IR temperature and week on PS in experiment 2 ($F_{4,10} = 5.68$, $P < 0.01$), and there was a tendency in experiment 1 ($F_{4,10} = 2.32$, $P < 0.086$) (Table 3). PS increased in week 1 (more piglets lying sternum) when IR temperature was decreased in both experiments. The proportion of piglets lying sternum increased from 24% to 37% when IR temperature decreased by 8°C, and increased from 25% to 52% with a 16°C decrease in IR temperature (Figure 5).

There was a further increase in PS when IR temperature was decreased in week 2 and this effect was even stronger in week 3 (Table 3). In weeks 2 and 3, the proportion of piglets lying sternum increased from 21% to 53% when IR temperature decreased by 8°C (experiment 1), and increased from 14% to 63% with a 16°C decrease in IR temperature (experiment 2) (Figure 5). In week 3, the proportion of piglets lying sternum increased from 27% to 62% when IR temperature decreased by 8°C, and increased from 13% to 79% with a 16°C decrease in IR temperature (Figure 5). Mean litter weight had a significant effect on PS in experiment 2 ($F_{1,10} = 22.81$, $P < 0.001$), but not in experiment 1. There was no effect of the time of day on posture behaviour.

Discussion

The environmental heat demand is dependant on radiation, conduction, convection and evaporation (Curtis, 1983). Hence, air temperature alone is an inadequate measure of the thermal challenge piglets are exposed to when radiant heat is supplied. The piglets responded moderately to a change in IR temperature at the age of 1 week by a significantly higher PS and an increased proportion of piglets lying fully sternum at low temperatures. This response was clearly more pronounced as the piglets got older (2 and 3 weeks of age). Hence, suckling piglets seem to use posture changes as a thermoregulatory strategy, but the ability was not so well developed at 1 week of age. Although the proportion of piglets lying recumbent increased as the piglets grew older, it was rare that all piglets in a litter were lying recumbent, even at the highest creep temperatures. This is contrary to findings in older animals where use of the recumbent posture increases with weight (Ekkel *et al.*, 2003).

Only small changes were seen in the huddling behaviour during the first 2 weeks after birth despite large changes in IR temperature. However, in the 3rd week there were clear changes in huddling behaviour with significantly higher HS and a higher proportion of piglets huddling when the

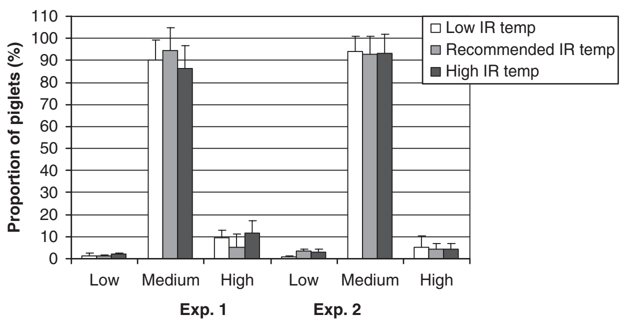

Figure 4 Proportion of piglets (%) in different degrees of huddling during week 3.

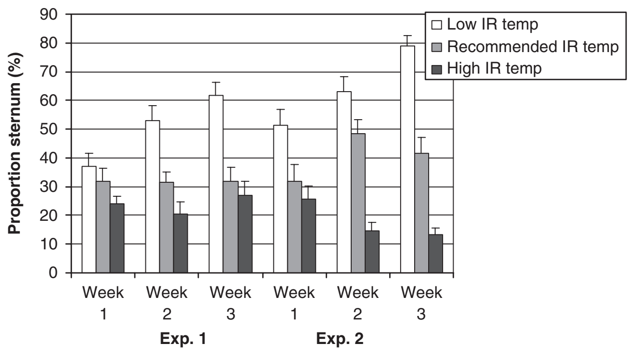

Figure 5 Proportion of piglets (%) lying in sternum posture in weeks 1, 2 and 3 in experiments 1 and 2.

Table 3 *Average posture score in the two set of experiments (means ± s.e.)*

		IR-temperature			Interactions week * IR temperature	
Experience	Treatment period	Low	Recommended	High	$F_{4,10}$	*P*-value
	Week 1	26.5 ± 1.3	24.0 ± 1.5	21.8 ± 1.0	2.32	0.086
1	Week 2	31.7 ± 1.3	25.8 ± 0.9	20.1 ± 1.3		
	Week 3	32.3 ± 1.0	24.6 ± 1.4	22.8 ± 1.5		
	Week 1	32.1 ± 0.8	28.4 ± 1.2	26.5 ± 1.2	5.68	<0.01
2	Week 2	35.2 ± 0.8	29.7 ± 1.3	22.2 ± 1.2		
	Week 3	37.1 ± 0.5	28.2 ± 1.1	17.7 ± 0.8		

IR = infrared.

temperature was decreased. Hence, it seems that huddling, as a thermoregulatory strategy, is used to a lesser extent than posture changes, the first 2 weeks after birth. Throughout the experiments, piglets exhibited the established positive thigmotaxic effect and showed a preference to settle near littermates. During the 1st week, the piglets were huddling together even at the warmest temperatures, which indicate a strong preference for staying close even though there was no obvious thermoregulatory need for this behaviour. A strong motivation for lying close to litter members regardless of temperature is also reported by others (Hrupka *et al*., 2000a and 2000b). In semi-natural conditions, the litter remains together in or near the nest for the 1st week of their life (Stangel and Jensen, 1991). This may have adaptive functions; staying close together may reduce the risk of hypothermia, getting lost or being detected by predators. The possibility for the litter to spread out within the nest might be spatially limited; thus, the strategy of reduced huddling may not be functional at this age. Separation from the sow is known to cause distress in suckling piglets, often registered as vocalizations (e.g. Weary *et al*., 1999). However, the piglets in this study were separated from the sow as a group and thus the distress was likely reduced. In addition, few vocalizations were registered during the testing period, an indicator that the piglets were not under separation distress.

Huddling behaviour was reduced in the warm temperatures during the 2nd and 3rd week. It is interesting that more than half the litter was huddling with three or more littermates at 21 days of age, at temperatures 8°C above the recommended temperature. The pig's fat reserves and heat producing ability is thought to be well developed by this age (Herpin *et al*., 2002). Increased litter weight was thought to reduce overall huddling behaviour, as others have shown a reduction in huddling behaviour with increased weight (Boon, 1981), but huddling behaviour increased with increased litter weight in our study.

In conclusion, postural changes, rather than changes in degree of huddling were the preferred thermoregulatory strategy for suckling piglets. In the warm temperatures the piglets would lay more recumbent to increase their heat loss, but they still remained huddled close together, even at 3 weeks of age. The tendency for piglets to lie close together despite high IR temperatures has implications for practical use as the resting pattern of pigs is thought to be a reliable response to the thermal comfort; however, this might not be a correct conclusion for young piglets. With IR temperatures 8°C higher than recommended, the experimental temperature was higher than what would normally be seen in commercial farms, and given a chance, the piglets would probably avoid the creep area altogether and lie in the sow area.

Acknowledgements

This work was supported by the Norwegian Research Council. We gratefully acknowledge Arne Svendsen for his help with constructing the experimental creep areas, and Andreas Flø for his help with the temperature sensor software. We would also like to thank Dr Inger Lise Andersen for valuable comments on the manuscript, and Dr Geir Steinheim for valuable help with the statistical analyses.

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'From caring comes courage' -Lao Tzu

Static Space Requirements for Piglet Creep Area as Influenced by Radiant Temperature

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Abstract. *Eight litters of 10 pre-weaned piglets from 6 to 22 days of age were evaluated for resting space occupied in an experimental 1 × 2 m creep box. Piglets were evaluated at setpoint temperatures of 30° C, 34° C, and 38° C at one week of age; 23° C, 27° C, and 31° C at two weeks of age; and 21° C, 25° C, and 29° C at three weeks old. Floor temperature, as provided by radiant heat lamps, was the primary environmental variable. Floor temperatures of 34° C, 27° C, and 25° C were evaluated as the recommended condition for piglet comfort for weeks 1, 2, and 3, respectively. The other two temperatures each week were considered mildly challenging in being too cool or too warm. The objective of the study was to quantify the space occupied by a litter of piglets under recommended conditions and when challenged by less comfortable radiant temperatures in an oversized, uniformly heated creep area. Creep box floor temperature was quantified as typically within 1° C of setpoint (variation within the space: SD = 0.7° C to 2.8° C) as measured with an infrared temperature sensor. The space occupied by a litter of 10 piglets at the recommended floor temperatures was $A_{LR} = 0.29*M^{0.53}$, where A_{LR} is the area occupied (m^2) and M is the individual piglet mass (kg). Under 4° C too warm or 4° C too cool conditions, the litter of piglets occupied approximately 12% more or 9% less area, respectively. The area recommended for 10 average-sized piglets at comfortable temperatures at 1 week (3.7 kg), 2 weeks (6.1 kg), and 3 weeks (8.6 kg) of age is 0.58, 0.76, and 0.91 m^2, respectively.*

Keywords. *Infrared heat, Piglet, Radiant, Resting pattern, Space requirement, Swine, Temperature.*

Provision of a heated creep area improves piglet survival via a higher temperature zone more suitable for neonatal piglets than the cooler environment preferred by the sow and by protection from being laid upon or stepped on during the sow's normal movements. As loose-housed sow and litter farrowing pens are increasing in use for improved welfare of the nursing sow, creep area design features need to be evaluated in relation to current pig production practices. Andersen et al. (2007) noted that Sweden, Norway, and Switzerland have outlawed use of farrowing crates; the rest of the European Union (EU) and U.S. production allow the use of crates.

Pre-wean piglet mortality of 6% is achievable (1 piglet in 16) by the best producers and is probably the lower limit of what can reasonably be accomplished. Pre-wean mortality of 14% is more common (2 piglets in 14), but losses up to 25% are seen (Andersen et al., 2007). Most of the mortalities occur during day 1 and 2 from crushing and starvation of the weakest litter members. Improved usage of the creep area should decrease mortality from both of these causes by protecting piglets from sow movements and minimizing cold-temperature stress, but creep area use is partially inhibited by the strong desire of newborn piglets (days 1 and 2, in particular) to stay near the sow and littermates.

Neonatal piglets prefer environmental temperatures near body temperature during their first few days after birth. Hrupka et al. (2000) observed that individual piglets of 1 or 2 days of age (*n* = 10 each age) explored throughout a rectangular chamber even though a favorable radiant temperature environment was available in one of the four subsections. These neonatal piglets did respond by settling (for more than 7 min) within the favorable end subsection where wall surface and air temperature were maintained at attractive temperatures.

Creep area allowance in farrowing pens is variable in area and appears to be rather informally determined by construction convenience. One common creep area option is a triangular-shaped, radiant-lamp heated, partitioned corner of the pen. Resting piglets can be observed lying both within and outside the protective boundary of the heated creep area. These creep areas are usually sufficient in size for the first few days after the piglets are born, the period of highest mortality and time of piglet preference to stay near the sow. After this early period, the creep area provides an important function, with a comfortable temperature to minimize piglet environmental stress and a clean protected area to reduce physical challenges. As the number of piglets born per litter has increased over the past two decades, it is not clear that creep area size has likewise increased to accommodate more resting piglets, particularly at older pre-wean ages. Throughout the pre-wean period, smaller, weaker piglets are less

Submitted for review in June 2007 as manuscript number SE 7068; approved for publication by the Structures & Environment Division ASABE in December 2007. Presented at the 2007 ASABE Annual Meeting as Paper No. 074085.

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  ISSN 0001-2351

competitive in obtaining the more desirable positions within the creep area environment. In an undersized creep, the smaller piglets are forced to rest in areas where they are potentially chilled, thus exacerbating their inferior position with additional stress and decreased weight gains, and if outside the protected area, they are exposed to more danger from crushing.

Zhang and Xin (2005) note that little scientific information has been available on piglet creep area requirements. They recommend a “double” sized mat (0.6 × 1.2 m) based on their study of heat mat use by two 12-piglet litters where the sow was confined in a farrowing crate. This double mat is twice as large as the mats typically provided by commercial swine farrowing units in North America (0.3 × 1.2 m). Zhang and Xin (2005) found that heat mat usage by pre-weaned piglets decreased from a high of 50% to 60% from day 2 to 5 and declined to a relatively constant 30% after 11 days of age.

The objective of our experiment was to quantify the effect of radiant temperatures on the space occupied by a litter of resting piglets in a uniformly heated creep area. Although it is documented that piglets will huddle and lie in sternum postures under cool conditions or spread out and lie in recumbent postures in warm conditions, this set of experiments sought to determine the actual area occupied by a litter of 10 piglets under recommended and mildly challenging temperature conditions. Floor temperature was evaluated via infrared (IR) sensors in addition to the dry-bulb ambient air temperature commonly documented in most piglet creep area studies. Documenting conditions via infrared sensors provided the effective temperature that the piglets were exposed to within a creep area heated with overhead radiant lamps, as is common practice on many commercial farms.

Methods

Experimental Design

The experiment was conducted during February and March 2007 at the Pig Research unit at the Norwegian University of Life Sciences. Eight litters with 12 to 15 healthy piglets, born within a 24 h period, were randomly allotted to the experiment. Each litter was evaluated for the space they occupied in a resting position three times a day for three days in a row over three weekly experimental periods, for 18 evaluations of each litter. Litters were assigned an identification number, 1 through 8, with the odd-numbered litters designated as group 1 while even-numbered litters were group 2 (table 1). During each experimental day, the ten largest piglets from one group 1 litter and one group 2 litter were removed from their farrowing pen, and each litter was placed in one of two identical experimental creep boxes in an adjacent room (see below). When all the piglets were settled after entering the creep box (typically 5 to 15 min) and lying steadily (another 10 to 15 min), digital photographs were taken to document piglet positions. The piglets were then returned to their respective farrowing pens, and ten piglets each from two other litters were subjected to the same treatment, followed by the two final pairs of litters.

The daily procedure of moving piglets from the farrowing pen to the experimental creep box started at 0800 h, just after sow feeding, and was repeated starting at 1200 h and 1600 h. This daily procedure was then repeated for the two following days. All eight litters were subjected to the treatments at the age of 6, 7, and 8 days (treatment period 1); 13, 14, and 15 days (treatment period 2); and 20, 21, and 22 days (treatment period 3). Piglet age was the average for the set of eight litters. In order to become accustomed to the handling and experimental box, the litters were taken into the creep box at 4 and 5 days of age with the same routine used in the experiment. Generally, throughout the experiment, the piglets were acclimated to the test setup and handling routine.

Within each treatment period, group 1 was subjected to a floor temperature 4°C warmer than recommended at day 1 within the treatment period, the recommended floor temperature at day 2, and 4°C lower than recommended on day 3. For group 2, the order of temperatures was reversed (table 1). Recommended temperatures were based on the heating system manufacturer (see below) setup for conditions commonly seen in practice.

A total of 216 images of the eight litters of piglets at three ages and nine temperatures were scored and analyzed for static space occupied during the three weeks of the study. The lying surface on the experimental creep box floor was divided into 10 × 10 cm squares with a white spray-painted grid. The net space occupied by the piglets was calculated as the sum of squares (0.01 m^2 per square) occupied by the piglets:

1 point for one square at least 90% covered by piglet.

1/2 point for one square 50% to 90% covered by piglet.

0 point for one square less than 50% covered by piglet.

Floor area occupied in the experimental creep area was statistically analyzed using a mixed-model analysis of variance with setpoint temperature as main effect and litter as random effect (SAS Institute, Inc., Cary, N.C.). Space occupied in relation to piglet mass was analyzed using a trend line analysis within a spreadsheet program.

Current Piglet Creep Area Characteristics

Each triangular creep area occupied a corner protected by a solid panel that the piglets could walk under. The creep area was partially covered by a hover containing a single heat lamp assembly with a red bulb (250 W infrared R125 IRR, Phillips, Eindhoven, The Netherlands). Litters 1, 3, 5, 7, and 8 had a larger creep area with a 66 cm high, 1.0 m^2 hover enclosing the heat lamp with 1.99 m^2 of total protected area.

Table 1. Experimental temperature schedule.

	Treatment Period 1			Treatment Period 2			Treatment Period 3		
Day[a]	Day 1	Day 2	Day 3	Day 1	Day 2	Day 3	Day 1	Day 2	Day 3
Piglet age	6 days	7 days	8 days	13 days	14 days	15 days	20 days	21 days	22 days
Group 1	38°C	34°C[b]	30°C	31°C	27°C[b]	23°C	29°C	25°C[b]	21°C
Group 2	30°C	34°C[b]	38°C	23°C	27°C[b]	31°C	21°C	25°C[b]	29°C

[a] Day within treatment period.
[b] Recommended floor temperature for age.

Table 2. Static space required (m^2) at different lying postures for an average litter of 10 piglets and for the heaviest litter of 10 piglets based on preliminary body dimensions measures at different ages.

	Age = 7 days		Age = 14 days		Age = 21 days	
Position	Avg. Litter	Heaviest Litter	Avg. Litter	Heaviest Litter	Avg. Litter	Heaviest Litter
Sternum	0.37	0.45	0.57	0.64	0.74	0.88
Recumbent	0.84	1.01	1.30	1.50	1.70	1.80

Litters 2, 4, and 6 had a 0.36 m^2 covered creep area of 54 cm height with the heat lamp and total protected area of 1.26 m^2. Floor surface temperatures at a location without piglets under the lamp in the hover were 30°C to 35°C where the red light from the bulb could be seen and 22°C to 27°C in the creep area but outside the hover (model 830-T2 handheld infrared sensor, two-point laser sighting, 1.5°C accuracy, Testo AG, Lenzkirch, Germany). The total loose pen area, which includes the sow space, was 6.0 m^2, which is the regulatory minimum allowance for a loose-housed sow pen in Norway. Ambient dry-bulb air temperature in the farrowing room was kept at 17°C for sow comfort. Target air temperature under the hover was 30°C.

Piglet Characteristics

A preliminary study determined body measures (Vasdal, 2007) of 95 piglets from 10 litters similar to the piglets used in the study reported here. Eight body measurements were conducted on the exact day the piglets were 7, 14, and 21 days old based on procedures in Moustsen and Poulsen (2004). Detailed protocols and results may be found in Vasdal (2007). The static space required for an average litter of 10 piglets and the heaviest litter of 10 piglets lying in fully sternum and fully recumbent positions at different ages are shown in table 2. Space requirements of the litters assumed touching but no overlap of litter members. The projected area of each piglet was a simple rectangle of width × length for sternum position and length × height for recumbent position. These piglet dimensions indicated that an experimental creep box design of at least 1.8 m^2 could accommodate 10 piglets of an above-average body weight litter when all were resting in recumbent position. All piglets were cross-bred Duroc boar with Landrace × Yorkshire sows. The 10 largest piglets were selected for experimental use due to their more likely survival than smaller siblings over the entire pre-weaning period.

Table 3. Total litter weights (kg) of piglets during each treatment period.

Litter	Treatment Period 1	Treatment Period 2	Treatment Period 3
1	40.9	64.7	92.2
2	36.6	63.1	90.5
3	37.5	60.8	95.6
4	40.4	68.6	79.0
5	35.6	57.8	83.9
6	41.8	67.0	88.2
7	31.4	54.9	79.4
8	31.5	51.2	75.9
Average	36.96	61.01	85.59
SD	4.03	6.04	7.10

To provide an indication of piglet mass in relation to the resulting space occupied, the experimental piglets were individually weighed on days 7, 14, and 21 (100 g resolution DIGI scale, DIGI Europe, Suffolk, U.K.), and the litter weights are presented in table 3. Variation in litter weight from lightest to heaviest of the eight litters was roughly equivalent to the largest litter having three additional average-sized piglets compared to the smallest litter.

Experimental Creep Box

Two creep boxes were constructed, each measuring 1 m wide × 2 m long × 1 m high with solid 12 mm thick finished plywood walls on three sides and a 5 mm thick transparent acrylic ceiling (fig. 1) for digital camera use. The fourth side was partially enclosed with a 30 cm plywood top partition that trapped rising heat in the creep area. The lower 30 cm was solid to contain the piglets, and a removable wood rail 2 × 5 cm protected the remaining open area from piglet escape. This lower partition and rail would not be part of a normal creep area, where the piglets would have free access between the overall farrowing pen and creep area. This experimental creep area was oversized to document piglet lying conditions without interference from limited space and was taller than normal for human entry to facilitate piglet

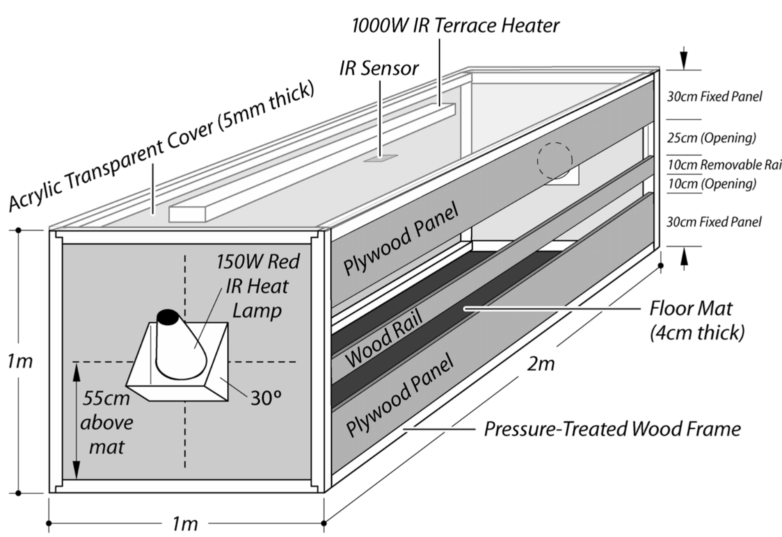


Figure 1. Experimental creep box.

removal. The flooring was a dairy-cow mattress assembly with a black, textured rubber 5 mm thick top layer over 5 cm thick foam blanket (cow mattress, de Laval, Tumba, Sweden).

Two heat lamps (model VE150 150 W lamp, Veng Systems, Roslev, Denmark; and Siccatherm 150 W lamp, red SG, 230 V, Osram, Slovakia) were mounted in each endwall of the experimental creep box at a 30° angle from vertical with the centerline of the lamp 55 cm above the floor mat surface. This configuration was determined from preliminary infrared camera (Thermovision A40, FLIR Systems AB, Danderyd, Sweden) analysis of similar 150 W heat lamps and was found to provide reasonably uniform temperature distribution in the box. The two 150 W lamps provided all heat during evaluation of floor temperatures of 21°C to 25°C in the experimental box but were supplemented for higher temperatures with a larger "terrace heater" mounted to tilt downward at a 30° angle below horizontal (1000 W, 8 × 121 cm with a 100 cm linear warming element, Infra Värmare, Stockholm, Sweden). During experiments at the higher temperatures, the terrace heater was adjusted using a rheostat to provide baseline heat to the creep box, and the two 150 W heat lamps were used for fine control to the final setpoint temperature.

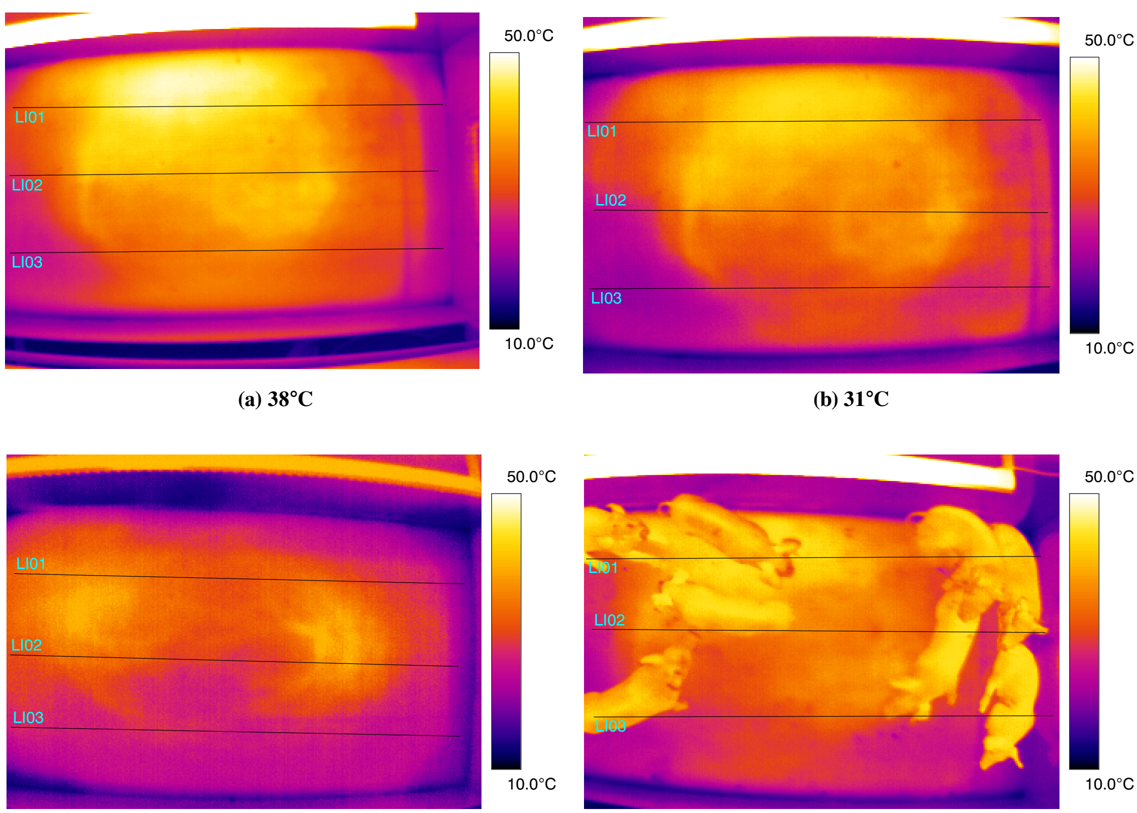
The two 150 W heat lamps were controlled in each experimental creep box by an infrared temperature controller (model VE122S IR controller, Veng Systems) using an infrared temperature sensor (model VE181-50 speed/light sensor, Veng Systems) mounted in the acrylic ceiling panel with temperature recorded at 1 min intervals. This IR sensor, mounted at 100 cm height with a circular view angle of 75°, detected floor surface temperature across the entire middle 1 m diameter section of the 2 m long experimental creep box.

Piglets were placed in the experimental creep box when the floor temperature was at the setpoint temperature (±1°C). The handheld IR sensor was used to check and record floor temperature in three to five locations near where the piglets were resting once the sleeping pattern was established. The experimental creep box dry-bulb air temperature sensor (thermistor, Veng Systems) was positioned close to piglet height, 55 cm from floor, in the corner of the experimental box where it was not in the line of sight of heat lamp radiant energy.

Results and Discussion

Temperature Conditions

Infrared images (Thermovision A40, FLIR Systems) from the warmest, coolest, and an intermediate temperature of the empty creep box are shown in figures 2a through 2c. Temperature distribution generally matched setpoint temperature for the 1 × 2 m area. The average (SD) floor temperatures were 36.9°C (2.8°C), 31.4°C (1.9°C), and 20.1°C (0.7°C), for the 38°C, 31°C, and 21°C images, respectively (figs. 2a, 2b, and 2c). These evaluations represent temperatures along three lines in each image, as shown in figure 3, demonstrating a 0.4°C to 1.1°C variation



(a) 38°C (b) 31°C (c) 21°C (d) Piglets in 36°C experimental box

Figure 2. Infrared camera images of temperature distribution within the experimental creep box at (a) warmest, (b) mid-range, and (c) coolest experimental conditions with dark color (purple) representing 10°C and light color (yellow) representing 50°C. The back wall with the terrace heater assembly is at the top of each image. (d) Piglets exploring within the experimental box, showing their impact on elevating the IR sensor detection of "floor" temperature. Temperatures along the three lines are shown in figure 3.

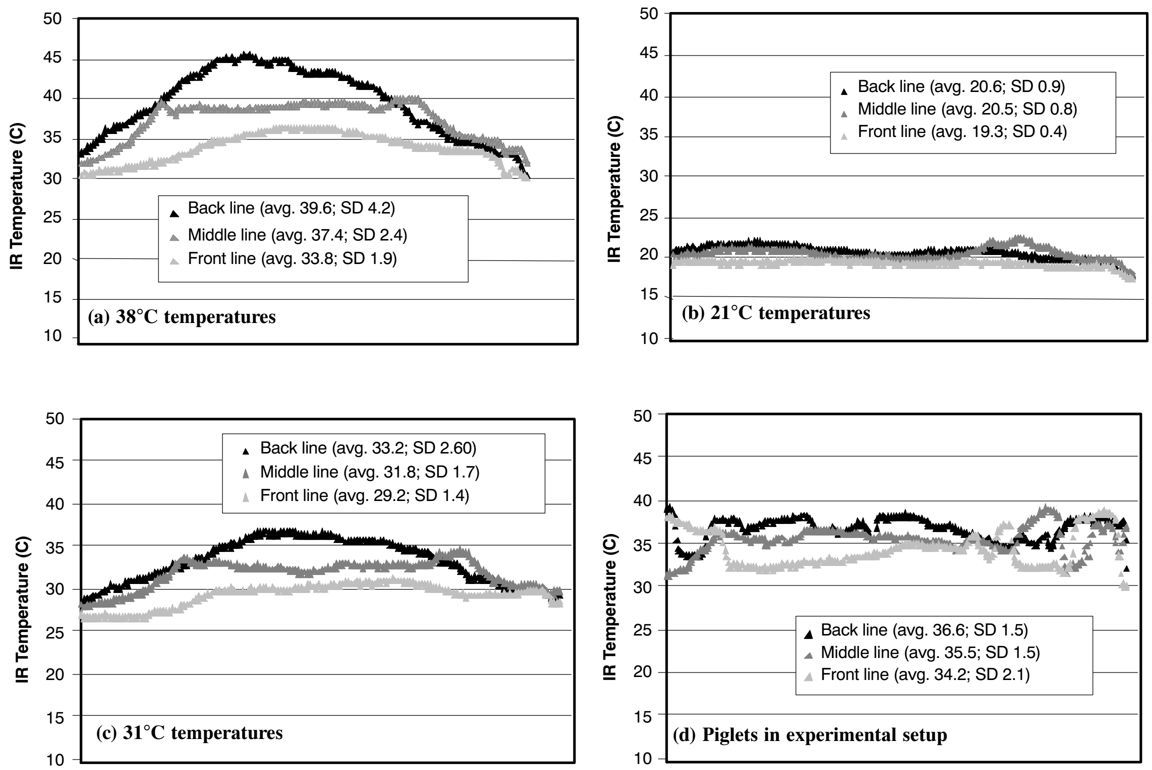


Figure 3. Temperatures along the three lines within each experimental creep box, as shown in figure 2. Lines represent conditions moving from left to right across the box and from the back (warmest temperatures), middle, and front (coolest temperatures) conditions within the box. Average (avg.) and standard deviation (SD) of each line is provided.

between setpoint and actual average floor temperature. The other six experimental temperatures had similar results (not shown). Temperatures increased from front to rear of the experimental box, with temperature at the walls cooler partly because no heat lamp radiant energy was directed to those areas.

Control of floor temperature with the IR sensor was very good (within 0.7°C) during treatment periods 1 and 2 (30°C, 34°C, and 38°C; and 23°C, 27°C, and 31°C, respectively) when the sensor view of the floor was relatively unobstructed (fig. 4). Difference between setpoint and observed IR temperature was 0°C to 0.4°C and 0°C to 0.7°C during treatment periods 1 and 2, respectively. Once the largest piglets (treatment period 3) entered the box, detection and control of floor temperatures (29°C, 25°C, and 21°C) was compromised by the IR sensor also detecting 37°C piglet body surface temperature. Differences between treatment period 3 setpoint and observed IR temperature were 2.8°C to 5.4°C, with the IR sensor indicating a temperature higher than the actual floor temperature (fig. 4). The ceiling-mounted IR sensor detected a 1 m diameter area, so when older piglets explored and finally lay down in this area, the sensor included their body temperature as part of the integrated floor temperature (figs. 2d and 3d). A detected rise in floor temperature above the setpoint caused the two end-wall mounted IR lamps to reduce heat output. The control of floor temperature in the box was sufficient to maintain desired conditions (within 1.5°C of setpoint) during the relatively short experimental timeframe, as verified through use of the handheld IR sensor (fig. 4), but IR temperature in the creep box was cooling to below the desired setpoint.

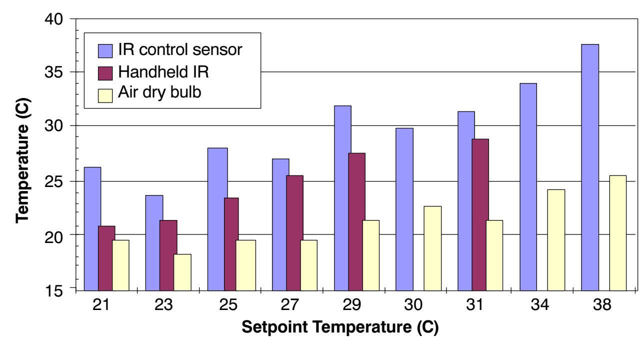


Figure 4. Setpoint floor temperature in comparison to the area-average floor temperature as indicated by the IR control sensor with the handheld IR sensor representing floor temperature between the piglets. Air dry-bulb temperature in the creep area is shown for comparison. Treatment period 1 did not use handheld IR sensor checks at 30°C, 34°C, and 38°C.

Reduction in energy use was the intent of this IR sensor development for commercial application. The creep was kept at proper temperature to attract piglets, but once they arrived, the lamp heat output was reduced as piglet body heat contributed to creep area warmth and hence reduced overheating. For future experiments, it is recommended that the sensor be installed in a lower position to view less floor surface area and mounted in an area less frequently used by resting piglets (front center of the box, in this case) to get full benefit of the control capabilities of the IR sensor system.

Although the setpoint IR floor temperatures varied by 8°C from warmest to coolest conditions during each treatment period, there was only a 2°C to 3°C difference in dry-bulb air temperature within the experimental box among the three

Table 4. Average (±SD) space occupied (m^2) for a litter of ten piglets (n = 8 litters).

	Floor Temperature			P-value
	30°C	34°C	38°C	
Day 7	0.57 ±0.12	0.61 ±0.13	0.66 ±0.13	0.010
	23°C	27°C	31°C	
Day 14	0.61 ±0.11	0.71 ±0.10	0.86 ±0.13	0.0001
	21°C	25°C	29°C	
Day 21	0.88 ±0.10	0.94 ±0.11	1.10 ±0.16	0.0005

setpoint temperatures. Air temperature was 7°C to 10°C lower than floor temperature of the creep space during all but the three coolest experimental temperatures, where the 1000 W terrace heater was not used.

Space Requirements

The floor temperature had a significant effect on total space occupied in all three treatment periods (table 4). As floor temperature increased 8°C during each treatment period, the total space occupied increased by 16% for 7 day old piglets, 41% for 14-day old piglets, and 25% for 21 day old piglets. An effect of litter was also evident on total space occupied for all treatment periods and accounts for some of the variation observed (day 7, p = 0.0001; day 14, p = 0.008; day 21, p = 0.005). The effect of litter was likely related to variation in litter weights (table 3) where the heaviest litters were 30%, 34%, and 26% heavier than the lightest litters during treatment periods 1, 2, and 3, respectively.

The litter resting pattern in all trials was concentrated in one area of the 2 m^2 experimental creep box despite the piglets having room to spread out if desired (fig. 5). The first individual to recline almost always settled along a wall, with subsequent littermates choosing another nearby wall position or a position near the resting individuals. Piglets exhibited the established positive thigmotaxic effect of attraction to closed-in spaces and contact with something solid and a preference to settle near littermates. The resting area chosen by the piglets varied during the trials (right rear portion of box, left side, etc.) but tended to favor rear wall and end wall portions of the experimental box. The static space occupied was related to piglet resting behavior, with the proportion of piglets lying fully recumbent increasing with increasing temperature, as expected, along with reduced huddling. Piglets seldom rested alone without any contact with other piglets at any of the tested ages. Generally, only one or two individuals would lie on top of other piglets at the coolest temperatures in each treatment period. Detail of resting behavior is found in Wheeler et al. (2007) to support these general observations.

For all the treatment periods, the measured area occupied by the litter of 10 piglets was midway between the estimated values in table 2. Even under warm conditions where more piglets rested in a fully recumbent position, the area occupied by the 10 littermates was reduced via space sharing by 21% (1 week old), 34% (2 week old), and 39% (3 week old) versus estimates in table 2, which allowed no interlocking postures.

The following power relationships were developed (best-fit trend line) from the data shown in figure 6 for piglet mass to space required for a litter of 10 piglets. The relationship is expressed in terms of individual piglet body mass, which is often known, in relation to the space occupied by an entire

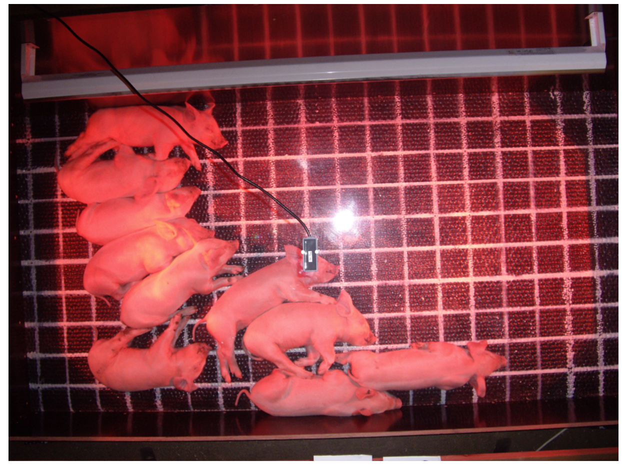


Figure 5. Example of resting pattern of one litter during treatment period 1. Seen are the 10 × 10 cm grid squares for space determination on the rubber mattress, the infrared sensor centered on the transparent acrylic cover, and the terrace heater lamp assembly at the back of the box (top of picture). Bright circle is reflection of camera flash in the cover.

litter to realistically quantify the true resting area occupied due to space sharing among individuals. Warm conditions are 4°C above recommended temperature, and cool conditions are 4°C below. The area needed by the litter of 10 piglets averaged 11.8% greater at the too-warm conditions and 8.5% less when 4°C cooler than recommended temperature.

Warm conditions: $A_{LW} = 0.33*M^{0.52}$ (1)

Recommended conditions: $A_{LR} = 0.29*M^{0.53}$ (2)

Cool conditions: $A_{LC} = 0.27*M^{0.52}$ (3)

where

A_{LW}, A_{LR}, A_{LC} = area occupied by litter of 10 piglets (m^2)

M = mass of individual piglet (kg).

Table 5 summarizes studies that estimated piglet or pig resting space occupied using relationships similar to those found above as:

$$A_L = C1*M^{C2} \quad (4)$$

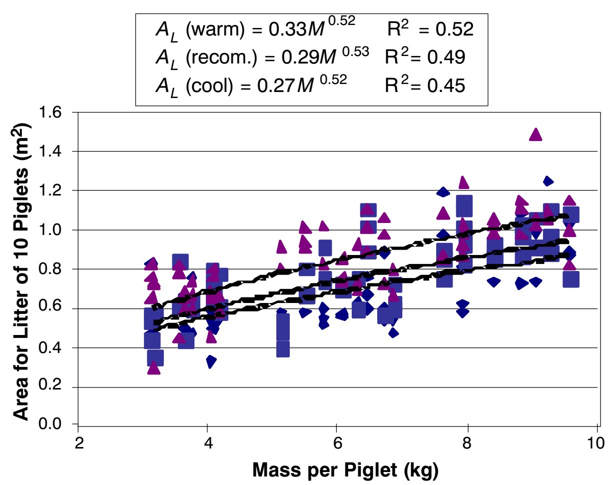


Figure 6. Average piglet mass (M) in each litter versus area occupied (A_L) by that 10-piglet litter resting in conditions that are too warm (upper line), at recommended temperature, and too cool (lower line).

Table 5. Summary of conditions and coefficients from studies that estimate piglet or pig resting area occupied using a relationship found in equation 4.

	C1	C2	R^2	Conditions
Wheeler et al. (this study)				10-piglet litter
Warm	0.33	0.52	0.52	
Recommended	0.29	0.53	0.49	
Cool	0.27	0.52	0.45	
Zhang and Xin (2005)	0.032	0.53	0.87	Individual piglet
Boon (1981)	0.3	0.67	N/A	12-piglet litter
Ekkel et al. (2003)	0.033	0.66	N/A	Individual 30 to 100 kg pigs
Pastorelli et al. (2006)	0.028	0.67	N/A	Individual 47 to 198 kg pigs

where

A_L = pig, piglet, or litter area occupied per conditions in table 5 (m^2)

M = mass individual pig or piglet (kg).

Zhang and Xin (2005) calculated a projected area of pre-weaned piglets from two litters using digitized video recordings to indicate piglet comfort level during heat mat use. The projected area was 0.044 m^2 pig^{-1} for one day old piglets and increased to 0.074 m^2 pig^{-1} for 14 day old piglets with heat mat temperatures of 33°C to 35°C. The results of our study correspond closely to the relation found by Zhang and Xin (2005) when an entire litter of 10 piglets is considered. Estimates indicate that a single 0.3 × 1.2 m mat commonly used in North American commercial farrowing facilities would be barely large enough for a litter of 10 piglets of one day of age and undersized for older litter ages. Zhang and Xin (2005) noted that the double mat used in their study was too confining once the test litter of 12 piglets became nine days old. They cautioned that not all piglets use the mats simultaneously and piglets may avoid overcrowding by adjusting their resting time. This did not match observations of litter behavior in the farrowing room and experimental setup during our study, where piglets were almost always synchronized in resting, exploring, or nursing at the youngest ages and then added more exploration activity into the third week of the experiment.

Estimates of resting area for weaned, growing pigs have resulted in relationships with body weight expressed as $kg^{0.67}$. Boon (1981) assumed a cylindrical shape while incorporating pig surface area and length-width ratio to estimate the maximum possible pig projected area as related to body mass of the 30 to 75 kg experimental pigs. Boon (1981) found that 20 kg pigs occupied 30% less area than estimated by his equation due to huddling postures even at a thermoneutral (lower critical) temperature.

Ekkel et al. (2003) used their own space sharing estimates to propose a relationship for 30 to 100 kg pigs in thermoneutral conditions in relation to other studied floor area estimates. The observed lying posture of the pigs at thermoneutral temperature was predominantly fully recumbent, but the Ekkel et al. (2003) estimate of area occupied was more typical of half-recumbent lying pigs due to observed space sharing. Pastorelli et al. (2006) estimated minimum space allowance for 47 to 198 kg pigs with digital image analysis.

Our project findings most closely match the Zhang and Xin (2005) relationship. Considering piglets ranging from 1 to 10 kg, our data from the too-warm evaluations averaged 1.6% (SD 0.7%) higher than area estimates from Zhang and Xin (2005). The Boon (1981) relationship differed from our data by 5% to 12% depending on piglet mass and whether comparison is made to our recommended, cool, or warm conditions.

Based on the relationships developed during our experiments, the recommended area for a litter of 10 average-sized piglets at comfortable temperatures at one week, two weeks, and three weeks of age is 0.58, 0.76, and 0.91 m^2, respectively. The area needed would be increased by about 12% under conditions 4°C warmer than recommended and decreased by about 9% under conditions 4°C cooler than recommended. The standard creep area allowance in Norway is 0.5 to 0.7 m^2 (O. Rognlien, Fjøssystemer AS, Fåvang, Norway, personal communication, 2007), but the space occupied during our study by a 10-piglet litter at 7 days of age under thermoneutral conditions was 0.6 m^2. As a consequence, the smaller, weaker piglets may be forced to rest in a less than optimal temperature and/or closer to the sow and are thus in greater danger of chilling and crushing. The total protected creep space provided to the piglets in our experiment was 1.99 or 1.26 m^2, depending on their pen arrangement with the sow. This is well above industry standard, yet some piglets at the older ages in the smaller creep were forced to rest in positions partially outside the confines of the creep area. All experimental litters had 12 to 15 individuals and our estimates are presented in terms of a 10-piglet litter, so space allowance must increase in proportion to litter size.

Summary and Conclusions

This project was able to quantify piglet resting space needs in relation to recommended temperatures and those considered mildly challenging for piglets from 6 to 22 days of age. Eight litters of 10 piglets each were exposed to recommended temperatures and conditions 4°C too warm and 4°C too cool in an experimental creep box of ample size and with more uniform environmental conditions than those typically found in commercial creep areas. The experimental creep box design provided a broad area of reasonably uniform heated space for comfortable conditions for all 10 piglets to settle. Average floor temperature within the creep box was generally within 1°C of setpoint temperature with variation (standard deviation) of about 0.7°C to 2.8°C around the 1 × 2 m floor area. Automated floor temperature control with an infrared sensor offered accurate establishment of creep area conditions so that piglets entered the experiment experiencing the desired conditions. During the trials, the IR sensor could control the creep box heat lamps to provide proper temperature conditions unless the piglet body mass occupied a large portion of the sensor's view area.

Floor temperature had a significant effect on total space occupied for piglets of one week, two weeks, and three weeks of age, averaging 3.7, 6.1, and 8.6 kg mass, respectively. Increasing floor temperature over an 8°C range also increased the space occupied for same age piglets.

Relationships were developed for the space needed by a litter of 10 piglets at the recommended, cool, and warm conditions in relation to body mass. That relationship at recommended temperatures was $A_{LR} = 0.29*M^{0.53}$, where A_{LR} is the area (m^2) occupied by a litter of 10 piglets, and M is the average individual piglet mass (kg). Under 4°C too-warm conditions, the piglets occupied 12% more area than observed under recommended temperatures and conversely occupied 9% less area when exposed to 4°C cooler conditions. The recommended area for a litter of 10 average-sized piglets at recommended temperatures at one week, two weeks, and three weeks of age is roughly 0.6, 0.8, and 0.9 m^2, respectively. A minimum creep area of 1.3 m^2 would accommodate the heaviest litter of 10 piglets in the experiment from an animal comfort perspective, but whether this translates into mortality reduction or productivity improvement is dependent upon other management factors, such as maintenance of desirable creep environment conditions.

Acknowledgements

Thanks to Arne Svendsen for fine work in experimental box construction and design assistance.

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PAPER III

'Very little of the great cruelty shown by men can really be attributed to cruel instinct. Most of it comes from thoughtlessness or inherited habit. The roots of cruelty, therefore, are not so much strong as widespread. But the time must come when inhumanity protected by custom and thoughtlessness will succumb before humanity championed by thought. Let us work that this time may come' ~Albert Schweitzer

Applied Animal Behaviour Science 122 (2010) 92–97

Contents lists available at ScienceDirect

Applied Animal Behaviour Science

journal homepage: www.elsevier.com/locate/applanim

Piglet preference for infrared temperature and flooring

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ARTICLE INFO

Article history:
Accepted 14 December 2009

Keywords:
Piglet
Preference
Infrared temperature
Flooring
Creep area

ABSTRACT

The aim of these experiments was to examine piglet preferences for different types of infrared temperatures and flooring at 24 h of age. In Experiment 1, 10 piglets from each of 18 litters were distributed between three pairwise infrared temperature treatments (6 litters in each pairwise test): 26 °C vs. 34 °C, 26 °C vs. 42 °C or 34 °C vs. 42 °C. In Experiment 2, another 18 litters were tested in an identical set-up with infrared temperatures of 30 °C vs. 34 °C, 30 °C vs. 38 °C and 34 °C vs. 38 °C. In Experiment 3, another 18 new litters were used to test the choice between foam mattress vs. sawdust, foam mattress vs. water mattress, and sawdust vs. water mattress. The preference test apparatus consisted of a box with three compartments: two test compartments and one neutral compartment in the middle. The piglets were released in the neutral compartment, and they were then allowed to explore all compartments and choose where to settle. Each litter was video recorded for 1 h and the piglets' locations were scored every second minute. The results of Experiment 1 showed that the piglets had a significant preference for 42 °C compared to 34 °C ($t = -5.3$, $P < 0.05$) and 26 °C ($t = -9.2$, $P < 0.01$). When subjected to smaller infrared temperature ranges in Experiment 2, the piglets showed no particular pattern in their choices. They significantly preferred to rest on a bed of sawdust compared to a foam mattress ($t = -2.9$, $P < 0.05$) in Experiment 3. The piglets showed no other significant preferences between the floorings. The results indicate that piglets have a preference for high infrared temperatures and sawdust flooring, but it is unclear how precisely the piglets can distinguish between infrared temperatures when the differences are relatively small, especially at this young age.

1. Introduction

High piglet mortality is still a problem in the swine industry, and most of this mortality occurs within the first two days after farrowing (English and Morrison, 1984; Dyck and Swierstra, 1987; Andersen et al., 2005). Around 50–80% of these early losses are normally attributed to starvation and crushing by the sow (e.g. Marchant et al., 2001), but hypothermia might often predispose piglets to starvation and crushing (e.g. Le Dividich and Noblet, 1981; Edwards, 2002). Heat loss is especially critical for piglets directly after birth, as their thermoregulatory capacity is poorly developed compared to other newborn mammals which are born with fur and brown adipose tissue (e.g. Berthon et al., 1994). When the temperature drops below the piglets' thermoneutral zone (34–36 °C), piglets try to increase their heat production by means of energetically demanding muscular shivering thermogenesis (Berthon et al., 1994), and they try to reduce their heat loss by social and individual thermoregulation (Mount, 1960; Vasdal et al., 2009).

Because room temperature in the farrowing unit is normally kept within the sows' thermal comfort zone, at around 20 °C (e.g. Svendsen and Svendsen, 1997), it is necessary to provide external heat sources and some sort of insulating flooring in the creep area to avoid hypothermic piglets. However, piglets prefer to lie close to the sow during

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doi:10.1016/j.applanim.2009.12.008

the first days after birth rather than in the heated creep area, despite unfavourable conditions in the sow area (Hrupka et al., 1998; Andersen et al., 2007; Moutsen et al., 2007), and will most commonly start to increase their use of the creep area from day 3 after birth (Hrupka et al., 1998; Berg et al., 2006). Newborn piglets are known to be attracted to thermal, olfactory, tactile and visual stimuli (e.g. Welch and Baxter, 1986; Parfet and Gonyou, 1991). By exploiting piglets' attraction to such stimuli, it is possible to increase the use of the creep area when the sow is present, either by reducing temperature in the sow area (Zhou and Xin, 1999; Schormann and Hoy, 2006; Burri et al., 2009), by adding a warm water bed in the creep area (Ziron and Hoy, 2003) or by providing a simulated udder in the creep area (Lay et al., 1999; Toscano and Lay, 2005).

If the goal is to increase piglets' use of the creep area during the first critical days after farrowing, it seems important to increase the attractiveness of the creep area itself. Thus, we need to find out what temperatures and flooring the piglets prefer and are attracted to early after birth. In order to rank animals' preference for one resource over another, several methods have been applied in the literature. For instance, the importance of different resources can be assessed by demand functions based on operant techniques (e.g. Holm et al., 2007), where animals are asked to operate a manipulandum a certain number of times for access to a given resource. However, in order for this approach to work, the animals would need to be trained to operate the manipulandum, which would be difficult to manage for piglets at 24 h of age, such as in this study. Alternatively, animals' preferences can be examined using a choice test, where time spent with each resource serves as an indicator of the preference for that resource (e.g. Dawkins, 1977).

Piglets' preferences for heat and flooring have been studied in earlier reports, however these reports have tested either single piglets (Welch and Baxter, 1986; Parfet and Gonyou, 1991; Hrupka et al., 2000a,b) or older piglets (Fraser, 1985; Beattie et al., 1998). As the preference of an animal may be affected by social environment (e.g. Pedersen et al., 2002; Sherwin, 2003), it appears more relevant to test the litter together when aiming at increasing the attractiveness of a creep area. Individually tested piglets may have very different responses and preferences compared to when they are together with their littermates, and their preferences may be obscured by the effects of separation stress (e.g. Weary et al., 1999). Because preference may also be affected by age and experience (e.g. Dawkins, 1977), it is also important to test piglets soon after birth, in order to ascertain if they are able to make an active choice based on their preferences at this critical age.

The aim of these experiments was to examine the preferences for different types of infrared temperatures and surfaces in litters of 24 h-old piglets.

2. Materials and methods

2.1. Experimental design

From each of 54 litters, 10 healthy piglets (Duroc boars mated with Landrace × Yorkshire sows) were randomly allotted to one of three experiments, with 18 litters at 24 h of age in each experiment. Experiment 1 tested the preference between the following three temperatures: 26, 34 and 42 °C (8–16 °C temperature difference). Experiment 2 tested the preference between another three temperatures: 30, 34 and 38 °C (4–8 °C temperature difference). Experiment 3 tested the preference between three types of flooring consisting of a layer of sawdust over concrete, a foam mattress and a water mattress. In each experiment, the three possible combinations were tested pairwise with 6 litters in each combination. Each litter was tested only once.

2.2. Animals and housing

The sows were kept loose in individual pens, measuring 8.9 m^2 in total with 4.3 m^2 solid floor. The total sow area was 6.8 m^2 and the heated creep area measured 2.1 m^2 in total. The floor in the creep area was covered with a 4 cm layer of sawdust, while the solid floor in the sow area was covered in a 2 cm layer of sawdust. The air temperature in the farrowing unit was kept at 20 °C until farrowing, and then reduced to 16 °C. The creep areas were heated by a 250 W heat lamp, providing an average infrared temperature of 26–28 °C.

2.3. The test box

Three identical boxes (2.4 m × 0.8 m × 0.8 m) were made with solid walls, and each box was separated into three chambers, measuring 0.6 m^2 (Fig. 1). The neutral compartment in the middle had a concrete floor and no roof, and the temperature was similar to the room temperature, around 18 °C. The two test compartments had a 5 mm thick transparent acrylic ceiling, both to reduce convective heat loss and to facilitate video recording of the piglets' location. Plastic curtains covered the entrances of the two test compartments in order to

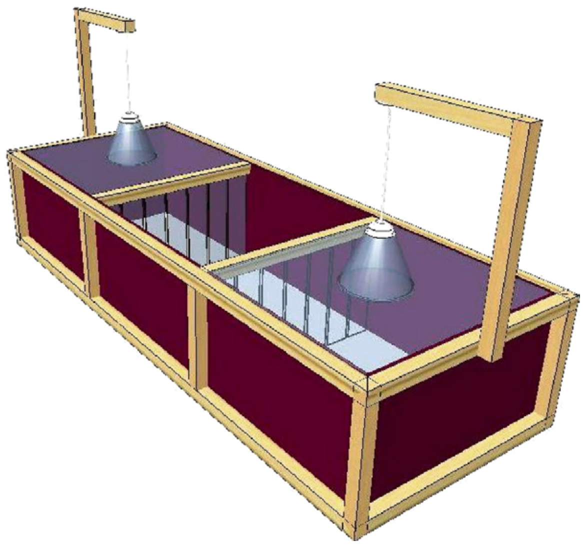

Fig. 1. One of the three identical test boxes with heat lamps in the ceiling and plastic curtains in the entrance of the test compartments.

create the correct thermal environments within and to avoid heating of the neutral area, while also making the compartments 100% visible for the piglets. During Experiments 1 and 2, both test compartments had a 5 mm rubber mat (de Laval®, www.delaval.com) on the floor.

The test compartments were heated by 250 W infrared heat lamps in the ceiling, and 500 W infrared heaters (Wimpel Golden Fie, www.wimpel.no) on one of the side walls were used to reach the higher temperatures. The temperatures were controlled by infrared temperature controllers (model VE122S IR controller, Veng Systems®, www.vengsystemer.dk) using an infrared temperature sensor (model VE181-50 speed/light sensor, Veng Systems®) mounted in the ceiling. The light intensity in the different temperatures was measured by a digital lux meter (TES® 1330 Digital Lux Meter). The illuminance ranged from 870 lux in the 26 °C compartment to 1170 lux in the 42 °C compartment, while the middle, neutral compartment was 280 lux.

In Experiment 3, the temperatures were kept constant at 34 °C. The three different floorings consisted of either a 5 cm layer of sawdust on the concrete floor (SAW), a 2 cm thick foam mattress with plastic coating (Helly Hansen®) (FOAM) or a water mattress filled with 8 l of warm water (MIK, www.mik-online.de) (WATER). In order to ensure that the piglets would not choose solely based on the familiarity of sawdust from their home pen, a small amount of sawdust (100 g) was sprinkled on both the foam mattress and the water mattress.

2.4. Experimental procedure

The piglets were tested as close to 24 h of age as possible; however, litters were on average between 20 and 30 h of age, due to some piglets being born during the night, while the testing commenced during the daytime. They were transported together from their home pen to the test box in an adjacent room. In order to provide the piglets with some experience with each temperature and flooring prior to the preference test, they were confined for 30 min in each of the two treatment compartments. The order in which the litters were placed in the treatment compartments was randomized between litters. After the 60 min had passed, the piglets were marked on their backs and returned to their home pen to suckle. When the sow had finished nursing, the marked piglets were again taken to the test area and placed in the neutral compartment between the two test compartments. The walls separating the two test compartments from the neutral area were then removed simultaneously, and the preference test began, lasting a total of 60 min. No people were in the visual range of the piglets during the test, and the test was monitored by video. Immediately after the test finished, the piglets were returned to their home pen.

2.5. Behavioural observations

The piglets were continuously video recorded in the test box for 60 min. A digital video camera was suspended over each test box and connected directly to a computer with the MSH Video software (www.guard.lv). The numbers of piglets located in each of the two test compartments and in the neutral area were scored using instantaneous sampling every second minute for a total of 30 observations per litter. Fifty percent or more of the body inside the compartment was the criterion for scoring location in either of the two compartments. In Experiment 1, 1 litter had to be excluded due to technical problems with the test box.

2.6. Statistical methods

The mean proportion of piglets per litter that was located in each of the compartments and the neutral area during the observation period was used as the statistical unit. Matched pair Wilcoxon signed rank tests were used to determine any significant preferences between the two compartments in each test. We also carried out a descriptive analysis of the preferences of individual litters, to investigate how consistent these preferences were. For a given litter, the scores of number of piglets in each location were summed across all observations and a compartment was said to be preferred if the total occupancy score for that compartment exceeded 60% of the total score for all compartments.

3. Results

3.1. Experiment 1: 26, 34 and 42 °C

The piglets showed a significant preference for 42 °C over both 26 °C ($t = -9.2$, $P < 0.01$) and 34 °C ($t = -5.3$, $P < 0.05$, Fig. 2), but the piglets showed no significant preference between 26 and 34 °C (Fig. 2). On average, less than $10 \pm 1.4\%$ of the piglets were lying in the neutral area during the tests. When 42 °C was one of the options, $19 \pm 1.7\%$ of the piglets were lying in the neutral area, due to some piglets lying partly outside the 42 °C area. More than 80% of the piglets had settled in one of the compartments within the first 10 min of the test in 14 of the 17 litters, where they remained throughout the test period.

When using the 60% criterion for preference it was clear that although there were no overall significant preferences in the 26 °C vs. 34 °C test, the occupancy scores indicated that 4 of the 6 litters preferred 34–26 °C, while 2 of the litters preferred 26 °C (Table 1). In the 26 °C vs. 42 °C test, 4

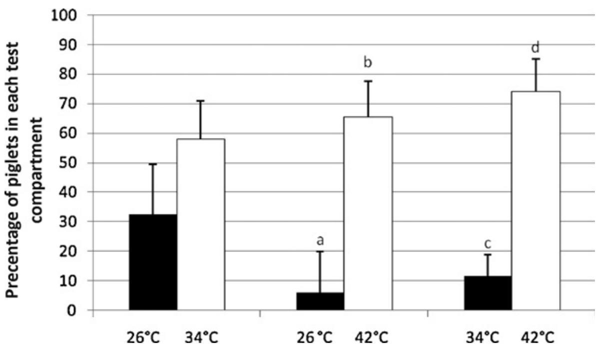

Fig. 2. The percentage of piglets per litter choosing test compartments at different temperatures ($n = 6$ litters) (Differences between temperatures are indicated by letters: a and b: $P < 0.05$; c and d: $P < 0.01$.).

Table 1
Descriptive analysis of preference for different infrared temperatures in Experiment 1.

Experiment	Preference	Number of litters
26 °C vs. 34 °C	26 °C	2/6
	34 °C	4/6
	Neutral area	0/6
	No clear preference	0/6
26 °C vs. 42 °C	26 °C	0/5
	42 °C	4/5
	Neutral area	0/5
	No clear preference	1/5
34 °C vs. 42 °C	34 °C	0/6
	42 °C	4/6
	Neutral area	0/6
	No clear preference	2/6

The criterion for temperature preference was that when scores of the number of piglets in each location were summed across all observations, the compartment at that temperature should score more than 60% of the total.

Table 2
Descriptive analysis of preference for different infrared temperatures in Experiment 2.

Experiment	Preference	Number of litters
30 °C vs. 34 °C	30 °C	3/6
	34 °C	2/6
	Neutral area	0/6
	No clear preference	1/6
30 °C vs. 38 °C	30 °C	3/6
	38 °C	3/6
	Neutral area	0/6
	No clear preference	0/6
34 °C vs. 38 °C	34 °C	2/6
	38 °C	3/6
	Neutral area	1/6
	No clear preference	0/6

The criterion for temperature preference was that when scores of the number of piglets in each location were summed across all observations, the compartment at that temperature should score more than 60% of the total.

of the 5 litters preferred 42 °C, and 1 litter showed no clear preference. In the 34 °C vs. 42 °C test, 4 of the 6 litters preferred 42 °C, while 2 litters showed no clear preference.

3.2. Experiment 2: 30, 34 and 38 °C

The piglets showed no significant preference when offered the choice between 30 °C vs. 34 °C, 30 °C vs. 38 °C and 34 °C vs. 38 °C (Fig. 3). On average, less than $5 \pm 0.8\%$ of the piglets were lying in the neutral area during these tests, while $18 \pm 3.8\%$ of the piglets were lying in the neutral area in the 34 °C vs. 38 °C test. More than 80% of the piglets had settled in one of the compartments within the first 10 min of the test in 14 of the 18 litters, where they remained throughout the test period.

When using the 60% criterion as mentioned above, there did not appear to be a pattern in the preference of the litters. Three of the 6 litters preferred 30 °C over 34 °C, while 2 litters preferred 34 °C and 1 litter did not show any clear preference (Table 2). In the test 30 °C vs. 38 °C, 3 litters preferred 30 °C while 3 litters preferred 38 °C (Table 2). When testing 34 °C against 38 °C, 2 litters preferred 34 °C; 3 litters preferred 38 °C and 1 litter did not show any clear preference.

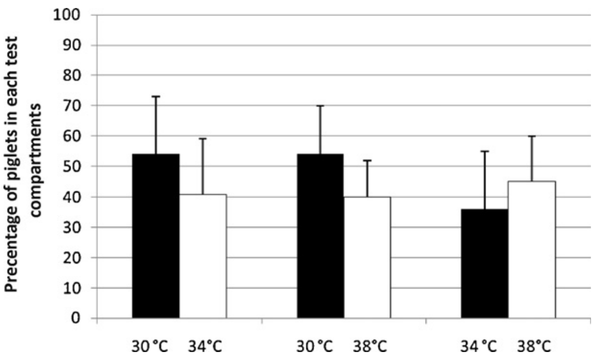

Fig. 3. The percentage of piglets per litter choosing test compartments at different temperatures ($n = 6$ litters).

3.3. Experiment 3: flooring

The piglets significantly preferred SAW to FOAM ($t = -2.9$, $P < 0.05$) (Fig. 4). However, there were no significant preferences between SAW and WATER, or between WATER and FOAM (Fig. 4). The piglets clearly avoided the neutral concrete area; less than $4 \pm 1.1\%$ of the piglets were lying in the neutral area during the three different tests. More than 80% of the piglets had settled in one of the compartments within the first 10 min of the test in 13 of the 18 litters, where they remained throughout the test period.

When using the 60% criterion for flooring preference, 5 of the 6 litters prefered SAW over FOAM, while only 1 litter preferred FOAM (Table 3). 4 of the 6 litters preferred SAW over WATER, while 2 litters preferred WATER (Table 3). When testing FOAM against WATER, 3 of 6 litters preferred WATER and 1 litter preferred FOAM, while 2 litters showed no clear preference between the two.

4. Discussion

The piglets preferred the warmer temperature in Experiment 1 when the temperature differences were

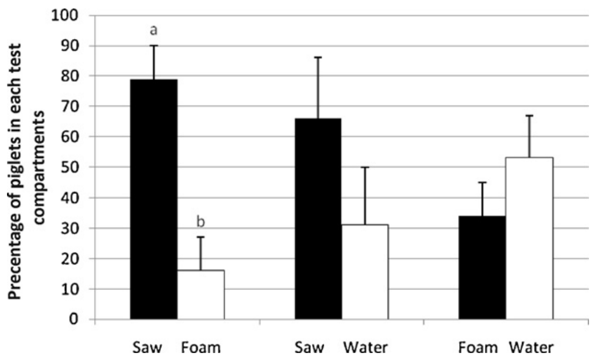

Fig. 4. The percentage of piglets per litter choosing test compartments with different floorings ($n = 6$ litters; SAW, sawdust; FOAM, foam mattress; WATER, water mattress) (Differences between floorings are indicated by letters: a and b: $P < 0.05$.).

Table 3
Descriptive analysis of preference for different floorings in Experiment 3.

Experiment	Preference	Number of litters
SAW vs. FOAM	Sawdust	5/6
	Foam mattress	1/6
	Neutral area	0/6
	No clear preference	0/6
SAW vs. WATER	Sawdust	4/6
	Water mattress	2/6
	Neutral area	0/6
	No clear preference	0/6
FOAM vs. WATER	Foam mattress	1/6
	Water mattress	3/6
	Neutral area	0/6
	No clear preference	2/6

The criterion for flooring preference was that when scores of the number of piglets in each location were summed across all observations, the compartment with that flooring should score more than 60% of the total (SAW, sawdust; FOAM, foam mattress; WATER, water mattress).

large (8–16 °C). This confirms earlier findings that piglets are able to choose their location based on the thermal environment (e.g. Titterington and Fraser, 1975; Farmer and Christison, 1982; Welch and Baxter, 1986), and that they seem to prefer temperatures above their thermoneutral zone (Hrupka et al., 2000b). Although the light intensity increased with increasing infrared temperatures, earlier studies have found that newborn piglets clearly prefer dark areas over bright light (e.g. Parfet and Gonyou, 1991), which is as an adaptive behaviour as it will encourage the piglets to remain in the dark nest. The fact that the piglets preferred the higher infrared temperatures despite the higher illumination levels suggests that the preference for temperature exceeds their preference for darkness.

There was no clear temperature preference in Experiment 2, when the temperature differences were smaller. This suggests that they were either unable to differentiate between these temperatures or had no preference for temperatures in the range tested. Under natural circumstances, piglets do not need to be fine tuned to specific temperatures; instead they would be attracted to the warmest surface in their surroundings, i.e. the sow's udder (e.g. Fiala and Hurnik, 1983). The presence of a cooler, neutral area between the two test compartments may have made the discrimination more difficult. However, the fact that the piglets clearly avoided the neutral area, which was 12–20 °C cooler than either of the test compartments, indicates that they had the ability to discriminate when the temperature difference was sufficiently great.

The piglets rarely changed their location once they had settled in one of the test compartments. A possible explanation for this might be that all the temperatures in the test compartments were higher than the room temperature, and will thus have been perceived as rewarding compared to the neutral area. The piglets also had to cross the colder neutral area to get to another compartment, which may have reduced the probability of further movement once they had entered a compartment. The fact that piglets preferred to stay together with their littermates fits well with an earlier finding; piglets prefer to lie close together despite having enough room to spread out even at temperatures over 40 °C (Vasdal et al., 2009). A relatively strong motivation to lie together is adaptive for the piglets due to the positive effects of social thermoregulation, the reduced chance of being detected by predators and the reduced risk of being trampled on or crushed by the sow. Consistent with this motivation for social contact, we observed that when the first piglets settled in one of the compartments, the other piglets soon followed, settled next to them, and remained there throughout the test period. Some of the piglets that chose the 42 °C compartment were observed to lie with part of their bodies outside the heated area, possibly indicating that the temperature was too high for their comfort. The motivation to lie together with other piglets thus may be stronger than the motivation to seek out a more optimal thermal environment.

When given the choice between different floorings, the piglets preferred sawdust to the foam mattress, but they showed no preference between sawdust and the water mattress. Sawdust is attractive due to its thermal qualities and the fact that it is soft and easy to manipulate. The preference for sawdust might also have been due to the familiarity of this substrate from their home pens, with its positive associations to maternal smells (e.g. Morrow-Tesch and McGlone, 1990). When tested with crated sows, a water mattress was preferred over foam mats, heated plates and straw in three-day-old piglets (Ziron and Hoy, 2003). However, as the water mattress in our study was heated by a heat lamp and not floor heating, the surface temperature might have been too high. Another potential problem with both the water and the foam mattresses could be the smell of plastic. Both types of mattresses were new, and as piglets have a well developed sense of smell (e.g. Parfet and Gonyou, 1991), the unfamiliar smell of plastic might have been aversive. Another possible explanation for the flooring preferences displayed by the piglets might be that the 30 min of experience before the test started was too little to induce any positive associations with the mattresses, compared to the 24 h experience they had had with the sawdust in their home pens. In the future, it would be interesting to consider whether experience with the two types of mattress in the home pen prior to the tests would have an effect on the preferences displayed.

In conclusion, these experiments show that piglets have the ability to assess their environment, and that they have clear preferences for specific infrared temperatures and floorings at 24 h of age. While there was no preference between 26 and 34 °C, the piglets clearly preferred 42 °C over both 34 and 26 °C, which suggests that their thermal preference is higher than their thermoneutral zone. Sawdust was also preferred to a foam mattress, although this may have been because they had already formed a positive association between sawdust and their home pen.

Acknowledgements

This work was supported by the Norwegian Research Council. The authors also want to thank Professor Torgeir Lyngtveit for making the figure of the test box.

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‘I have always held firmly to the thought that each one of us can do a little to bring some portion of misery to an end’

– Albert Schweitzer

PAPER IV

Applied Animal Behaviour Science 120 (2009) 62–67

Contents lists available at ScienceDirect

Applied Animal Behaviour Science

journal homepage: www.elsevier.com/locate/applanim

Piglet use of the creep area—Effects of breeding value and farrowing environment

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ARTICLE INFO

Article history:
Accepted 29 May 2009
Available online 28 June 2009

Keywords:
Breeding value
Creep area
Farrowing environment
Piglet mortality

ABSTRACT

The objective of this study was to investigate piglet use of the creep area, comparing litters of sows with a high vs. low breeding value for piglet survival in the first 5 days postpartum, that were either housed in crates or individual pens during farrowing and lactation. Seventy-five Yorkshire × Danish Landrace sows were video recorded for 4 days after farrowing, and the analysis was conducted using instantaneous sampling every 10 min commencing 24 h after the birth of the first piglet for a period of 72 h. Breeding value for piglet survival had no effect on piglet use of the creep area or time spent in any location of the farrowing environment. Farrowing environment had significant effects on piglet location; during all days there were significantly more piglets in the creep area in the crates compared to the pens ($P < 0.01$), and this difference was larger at 24–48 h than at 49–72 h and at 73–96 h after birth ($P < 0.05$). Piglets in pens spent significantly more time resting near the sow, excluded nursing ($P < 0.001$), and this percentage decreased over time after farrowing ($P < 0.001$) in both the crates and the pens. In conclusion, piglet use of the creep area was higher in the crate compared to the pen particularly during the second day of life. This may partly be due to a much larger proportion of uncomfortable, slatted floor in the crates, and the shorter distance from the sow to the creep area in the crate.

1. Introduction

A significant proportion of the piglet mortality occurs within the first 2 days after farrowing (English and Morrison, 1984; Dyck and Swierstra, 1987; Andersen et al., 2005), and starvation and crushing by the sow may explain around 50–80% of these losses (e.g. Marchant et al., 2001). In addition to improving maternal abilities of the sows (e.g. Valros et al., 2003; Jarvis et al., 2005) and providing extended management around the time of farrowing (White et al., 1996; Andersen et al., 2007; Andersen et al., 2009), many farmers try to encourage the piglets to use the creep area when suckling is not in progress as soon as possible after farrowing. It is commonly assumed that minimizing the frequency and duration of piglets stay in the sow area reduces the risk of being crushed or trampled by the sow the first days after parturition, but at present this has not been documented.

There are many ways of making the creep area more attractive to the piglets (Morrison et al., 1983; Lay et al., 1999), but most importantly it should be a warm, dry and soft resting area (Ziron and Hoy, 2003) without draught, and that is easily accessible (Zhang and Xin, 2001). However, piglets prefer to lie next to an anaesthetized piglet in a cold area than alone in a warm area (Hrupka et al., 2000), which also illustrates a high motivation for piglets to lie close to other littermates regardless of temperature. Piglets prefer lying close to the sow for the first 2 days after farrowing despite unfavorable conditions in the sow area (Hrupka et al., 1998; Berg et al., 2006; Moutsen et al., 2007). At this age, piglets tend to use the creep area more in crates than pens (Blackshaw et al.,

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doi:10.1016/j.applanim.2009.05.014

1994) and more in pens with slatted floor and no heat in the sow area than in pens with solid floor and heat in the sow area (Houbak et al., 2006; Moutsen et al., 2007). Piglets will increase their use of the creep area from day 3 (Hrupka et al., 1998; Berg et al., 2006) and there is a large variation in the use of the creep area between litters within the same herd (Andersen et al., 2007).

The large variation in the use of the creep area is interesting, and it has been suggested that the sow has an effect on piglet use of the creep area (Berg et al., 2006). For example mothers with good maternal skills may be more effective in gathering the piglets in a group when entering the nest and before she lies down. This may potentially reduce the risk of crushing. Individual differences in maternal behaviour may be more evident when the sow is able to move freely and interact with her piglets (e.g. Boe, 1993, 1994). Increased piglet survival may be achieved indirectly by selecting for optimal maternal behaviour (i.e. more attentive mothers) to prevent crushing or by selecting for piglet survival directly. However, when selecting sows based on their breeding value for piglet survival at day 5 such as in the present study, we do not know whether the improved survival is achieved through improved maternal skills, the prenatal environment, factors related to the birth process or a combination of many factors. If increased piglet survival is partly a result of improved maternal behaviour, we would expect to see some differences in sow and piglet behaviour between the two breeding lines.

The physical environment of the sow and litter has been given much research attention during the last 20 years and the debate concerning crates versus pens is still active, both with respect to the welfare of the sow (e.g. Blackshaw et al., 1994; Jarvis et al., 1997) and piglet mortality (e.g. Cronin and Smith, 1992; Weary et al., 1996b; Marchant et al., 2000; Weber et al., 2007). The restrictive farrowing crate has negative effects on sow health (Verhovsek et al., 2007), stress level during farrowing and lactation (Jarvis et al., 1997) and increases farrowing duration (Hansen and Vestergaard, 1984; Biensen et al., 1996). Some studies have reported higher piglet mortality due to crushing in pens than in crates (Cronin and Smith, 1992; Cronin et al., 1996), whereas others find similar results in both types of housing (e.g. Schmidt, 1992; Biensen et al., 1996; Cronin et al., 2000; Weber et al., 2007; Pedersen et al., 2008).

According to the Norwegian Regulation for Animal Welfare, all nursing sows must be kept in a loose house farrowing pen, but in Denmark and other countries, the use of farrowing crates is still accepted. Both in Norway and Denmark around 14–15% of all live born piglets die before weaning (Norsvins In-Gris Årsstatistikk, 2005; Sloth and Bertelsen, 2007) and breeding for increased litter size is one of the major factors that cause higher mortality irrespective of the farrowing environment (e.g. Pedersen et al., 2006; Weber et al., 2007).

The aim of the present study was to investigate piglet use of the creep area in litters of sows with a high versus low breeding value for piglet survival until day 5, which were either housed in crates or individual pens during farrowing and lactation. Based on earlier findings (e.g. Blackshaw et al., 1994), we predicted that piglets born in crates would spend more time in the creep area than piglets born in pens. We also predicted that piglets born in pens would spend more time resting in contact with the sow during the first 3 days after birth than piglets born in crates.

2. Materials and methods

2.1. Experimental design

This experiment took place at the Research Centre Foulum in Denmark. During four farrowing batches in 2007, 75 gilts were video recorded from farrowing to 4 days after farrowing (0–96 h) in either a farrowing pen or crate to document piglet use of the creep area.

2.2. Animals

The sows were Yorkshire × Danish Landrace gilts, and they were inseminated in their second oestrus at around 210 days of age with semen from Duroc × Hampshire boars. Two breeding lines of sows were used in the experiment (Su et al., 2007): 43 HB gilts (high piglet survival until day 5) and 32 LB gilts (low piglet survival until day 5). Of the HB gilts, 24 were crated and 19 were kept in pens. Of the LB gilts, 19 were crated and 13 were kept in pens.

All piglets were marked with numbers immediately after birth. Birth assistance during farrowing was only given if more than 3 h had passed since the last piglet was born. No other assistance during the lactation period was given, and a piglet without any possibility to live due to injuries, starvation or hypothermia was euthanized by the staff.

2.3. Housing

During the gestation period the gilts were housed together in groups of 30 with automatic feeders. The gilts were brought to their farrowing environment at day 110 post-insemination, 6 days before expected farrowing. The farrowing pens measured 7.3 m^2 in total with 1.9 m^2 slatted floor and had solid sloping walls on three sides. The sow area was 6.2 m^2 and the creep area was 1.2 m^2 (Fig. 1).

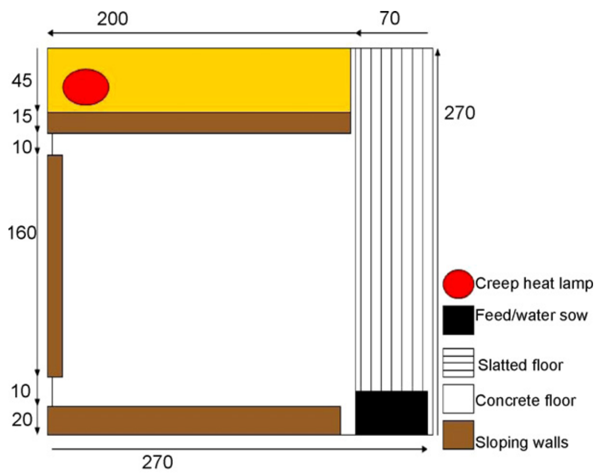

Fig. 1. The farrowing pen (all measures in cm).

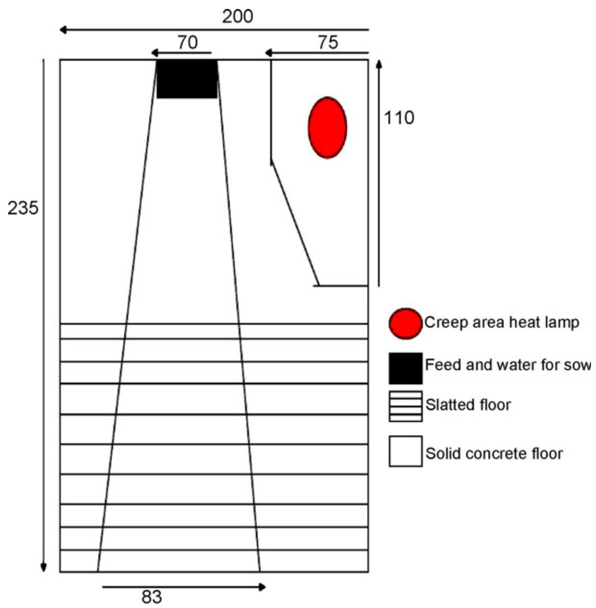

Fig. 2. The farrowing crate (all measures in cm).

The farrowing crates measured 4.7 m^2 in total with 2.3 m^2 slatted floor. The sow area was 1.5 m^2 and the creep area was 0.8 m^2 (Fig. 2). Temperatures in both environments were kept at 18–20 °C, and the surface temperature in the creep area was kept at 30 °C in both environments.

The creep area in both the pen and the crate was heated by a heat lamp in the roof of the creep area and the floor was covered with a 3–5 cm layer of chopped straw. Thus there would be no major differences in the attractiveness of the creep area. The sows were given 2 kg of chopped straw daily from day 113 until farrowing. The sows were fed automatically at 7.30 am and 14.30 pm. Lights were kept on for 24 h to allow video recording.

2.4. Behavioural observations

The sows were continuously video recorded for 4 days after farrowing. A video camera (TVCCD-14IR, Monacor, Bremen, Germany) was suspended over each pen and connected to a computer. The videos were analyzed using the MSH Video software (www.guard.lv), and all activity in the crates and pens was analyzed by using instantaneous sampling every 10 min from 24 h after the first piglet was born until 72 h had passed (96 h). This time period was selected because this is the time when piglet mortality is highest (e.g. Dyck and Swierstra, 1987).

The number of piglets observed in the following places was recorded: (1) In the creep area. (2) Resting together on the concrete floor with body contact. (3) Resting together on the slatted floor with body contact. (4) Resting alone without body contact. (5) Resting in contact with the sow when not suckling. (6) Active on the solid floor. (7) Active on the slatted floor.

2.5. Statistical methods

In the analysis, the litter was used as the statistical unit. The difference in activity between classes of breeding value, farrowing environment and days, were analyzed using a mixed model procedure in SAS software (Hatcher and Stephanski, 1994), including the following class variables and their interactions: batch (1–4), breeding value (high or low), farrowing environment of the sow (crates or pens) and hours after farrowing (24–48 h, 49–72 h or 73–96 h after birth of first piglet). Class variables or interactions with no significant influence on the model ($P < 0.10$) were removed from the final model. Sow nested within breeding value and farrowing environment was included as a random effect. The covariance structure of the repeated measurements on days was modeled using compound symmetry.

3. Results

3.1. Effects of breeding value on piglet location

The breeding value of the sow had no significant effect on time (% of the observations) spent in any part of the farrowing environment (Table 1) and there were no significant interactions between breeding value, environment or hours after farrowing.

3.2. Effects of farrowing environment and hours after farrowing on piglet location

There was a significant interaction between hours after farrowing and farrowing environment concerning the percentage of piglets resting in the creep area ($F_{2.126} = 7.2$; $P < 0.01$). During all days there were significantly more piglets resting in the creep area in the crates compared to the pens ($F_{1.66} = 15.70$, $P < 0.01$, Fig. 3).

Table 1
Piglet activities (% of observations) with respect to farrowing environment and breeding lines (means ± S.E.).

	Breeding value		Environment		Breeding value		Environment		Interactions breeding value × environment
	HBV	LBV	Crate	Pen	$F_{1.66}$	P-value	$F_{1.66}$	P-value	P-value
In creep	50.5 ± 2.1	49.0 ± 2.1	57.3 ± 1.7	39.5 ± 2.3	0.1	ns	15.7	<0.01	ns
Rest solid floor	2.2 ± 0.4	1.4 ± 0.2	1.1 ± 0.3	2.7 ± 0.5	3.1	ns	2.1	ns	ns
Rest slatted floor	0.03 ± 0.02	0.02 ± 0.08	0.02 ± 0.01	0.04 ± 0.02	0.6	ns	0.3	ns	ns
Rest alone	0.4 ± 0.1	0.3 ± 0.1	0.1 ± 0.01	0.4 ± 0.1	1.8	ns	5.2	<0.05	ns
Rest contact sow	19.8 ± 1.6	20.9 ± 1.8	14.3 ± 1.4	28.6 ± 1.6	0.01	ns	17.6	<0.001	ns
Active solid floor	17.2 ± 1.1	17.5 ± 1.9	10.0 ± 0.6	27.5 ± 0.1	0.02	ns	130.2	<0.001	ns
Active slatted floor	10.2 ± 0.9	11.1 ± 1.0	17.2 ± 0.7	1.5 ± 0.2	0.3	ns	128.5	<0.001	ns

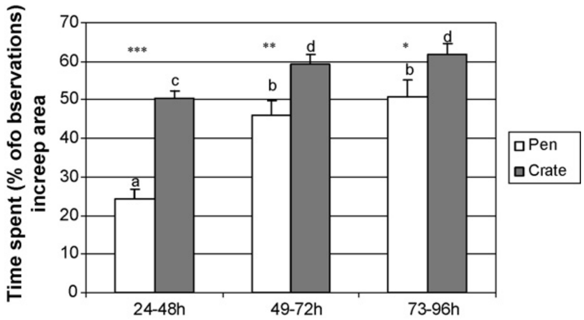

Fig. 3. Changes in time spent (% of observations) in creep area (mean ± S.E.) in crate and pen during the first 3 days after birth. Difference within day between environments: $^{*}P < 0.05$, $^{**}P < 0.01$, $^{***}P < 0.001$. Difference between days within environment—a, b and c: $P < 0.05$.

However, the difference between crates and pens was larger at 24–48 h (LS means differences; $t_{2.126} = 5.45$, $P < 0.0001$) than at 49–72 h (LS means differences; $t_{2.126} = 2.15$, $P < 0.05$) and at 73–96 h (LS means differences; $t_{2.126} = 2.28$, $P < 0.05$, Fig. 3). The percentage of piglets resting in contact with the sows when not nursing decreased over time after farrowing (24–48 h: 27.3 ± 2.0, 49–72 h: 18.3 ± 1.9, 73–96 h: 14.7 ± 1.9) ($F_{2.126} = 24.7$; $P < 0.001$). This percentage was significantly higher in pens compared to crates at all ages ($F_{2.126} = 17.6$, $P < 0.001$). The percentage of piglets being active on the solid floor was significantly higher in pens compared to crates ($F_{1.66} = 130$; $P < 0.001$) and this percentage was reduced over time ($F_{2.126} = 30.0$, $P < 0.001$). In contrast, the percentage of piglets being active on the slatted floor was significantly higher in crates compared to pens ($F_{2.66} = 129.5$, $P < 0.001$) with no significant effect of hours after farrowing.

Only a small percentage of piglets rested alone during the 3 days (24–48 h: 0.2 ± 0.01; 49–72 h: 0.2 ± 0.1; 73–96 h: 0.2 ± 0.04), with no effect of environment or breeding value. Few piglets rested together on the floor without contact with the sow during the 3 days (24–48 h: 2.3 ± 0.5; 49–72 h: 1.5 ± 0.5; 73–96 h: 1.6 ± 0.4) and there was no significant effect of neither environment nor breeding value.

4. Discussion

As predicted, the piglets spent less time in the creep area and more time resting in contact with the sow in the pen system compared to crates. A lower use of the creep area in pens where sows are kept loose has previously been documented (e.g. Blackshaw et al., 1994), and may be due to the increased ability of the sow to interact and communicate with the piglets. Piglets are highly motivated to stay close to the sow the first days after birth, and will not increase the use of the creep area until after days 2–3 (Hrupka et al., 1998; Berg et al., 2006). The fact that piglets in pens spend more time resting in contact with the sow other than when suckling, may pose a challenge for loose-housing of lactating sows, as more piglets in the sow area increases the risk of crushing (e.g. Weary et al., 1996a). However, according to Berg et al. (2006), there is no significant relationship between piglet use of the creep area or location in the pen and piglet mortality. Neither does the quality (i.e. heat conserving capacity) of the creep area seem to affect piglet mortality in commercial loose-housed sow herds (Andersen et al., 2007).

If this is the case, then work to improve the attractiveness and quality of the creep area may not help to improve piglet survival. However, more systematic, experimental work is needed before any conclusion can be made. It may be more important to focus on improving maternal skills, especially when sows are kept loose. This can be done by selecting for maternal behaviour directly. A heritability of 0.24 has been shown for a maternal care index including nest building, nursing and licking responses in mice (Chiang et al., 2002). Comparatively, few have tried to develop a similar index for maternal behaviour in pigs. Vangen et al. (2005) documented moderate heritability for sows' reaction to piglets screams based on qualitative measures from questionnaires in commercial herds. Maternal behaviour can also be improved by offering a better farrowing environment, such as providing enough nest building material (Cronin et al., 1993; Herskin et al., 1998, 1999).

Traditionally, it has been assumed that more time spent away from the sow (i.e. in the creep area) excluded suckling would increase piglet survival, but in fact there is at present no documentation to support this. In our experiment we did not find any effects of the sows breeding value on the piglet use of the creep area. This effect could only have been achieved if breeding for increased survival had a direct effect on the sow's maternal behaviour. Another important point is that we do not know specifically how much contact between the sow and piglet other than when suckling is optimal for piglet survival. Individual farrowing pens are based on the principle that the piglets should leave the sow and enter the creep area when the sow is not nursing, while under natural conditions and in group-housing, lactation systems it is the sow that leaves the piglets (Stolba and Wood-Gush, 1989; Stangel and Jensen, 1991; Pitts et al., 2002). In fact, increased time spent away from the piglets increased the sow's responsiveness towards the piglets and increased piglet survival (Pajor et al., 2000; Pitts et al., 2002). This aspect should indeed be taken into consideration when developing future farrowing pens.

The creep areas in the two environments were both equipped with heat lamp and the same amount of straw, making the quality of the creep area equal. However, an important difference between the two environments was that in crates, half the total floor surface was slatted, whereas in the pen only 25% was slatted. The creep area in the crate may thus be perceived as more attractive compared to rest of the crate, due to the higher percentage of slatted floor area. Also, the horizontal bars next to the sow may interfere with the piglets' opportunity to lie close to the sow's udder where heat is provided. This may partly explain a larger use of the creep area in crates than pens. The different proportion of slatted floor vs. solid concrete floor also explains why piglets were more active on slats and less active on solid floor in crates than pens. Another factor that may influence the use of the creep area is the distance between the creep area and the most commonly used resting place for the sow in the pen (Zhang and Xin, 2001). In crates, the distance from the resting sow to the creep is usually less than in a pen. Although the different qualities of the two types of pens may explain the different use of the creep area, impairing the quality of the sow area is not an acceptable solution to improve piglet's survival. Unless the quality and attractiveness of the creep area increases the use of this area and decreases piglet mortality, we should rather focus on the more direct, predisposing factors for piglet mortality, such as litter size (Pedersen et al., 2006; Weber et al., 2009), piglet characteristics (Pedersen et al., 2008), maternal behaviour (Chiang et al., 2002) and management (Andersen et al., 2007; Andersen et al., 2009; White et al., 1996).

In conclusion, sow breeding value did not affect piglet use of creep area. Piglet use of the creep area was higher in the crate than pen system during the second, third and fourth day of life. This may be due to the larger proportion of uncomfortable, slatted floor in the crates and a shorter distance from the sow to the creep area in the crate.

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‘We must not lose faith in humanity. Humanity is an ocean; if a few drops of the ocean are dirty, the ocean does not become dirty’

– Mahatma Gandhi

Applied Animal Behaviour Science 125 (2010) 96–102

Contents lists available at ScienceDirect

Applied Animal Behaviour Science

journal homepage: www.elsevier.com/locate/applanim

Increasing the piglets' use of the creep area—A battle against biology?

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ARTICLE INFO

Article history:
Accepted 20 April 2010
Available online 10 May 2010

Keywords:
Pig welfare
Piglet mortality
Creep area
Farrowing pens

ABSTRACT

Indoor farrowing systems are based upon the assumption that the newborn piglets will leave their mother after suckling and enter a heated creep area, but newborn piglets are motivated to remain close to the sow. Several creep area features attractive to piglets were used to attempt to increase time spent in the creep area the first two days after birth and to find out whether increased time spent in the creep area would affect early piglet mortality in farrowing pens. Forty-six loose-housed sows and their litters kept in individual farrowing pens were subjected to one of three creep area treatments; (1) control (CON); concrete floor in the creep area, (2) bedding (BED); an insulated and soft bedding in the creep area and (3) HUT; an insulated and soft bedding in the creep area plus an additional wall to increase the heat conserving capacity in the creep area. The pens were video-recorded from 0–72 h after birth and analysis was conducted from 08:00 h to 14:00 h and from 20:00 h to 02:00 h on each day. The attempts to make the creep area attractive did not increase the use of the creep area; piglets in the hut treatment spent less time in the creep area and more time resting near the sow than piglets in the CON and BED treatment. Improving the thermal comfort and increase the layer of bedding in the creep area did not increase time spent away from the sow, nor did it reduce piglet mortality. Quality of the creep area thus appears to have little impact on piglet survival.

1. Introduction

The domestic sow shows maternal behaviour similar to that of the wild boar (e.g. Jensen, 1986; Gustavsson et al., 1999), and under semi-natural conditions, domestic sows will leave the group to search for a suitable nest site 1–2 days prior to farrowing (e.g. Jensen, 1988). When a suitable nest site has been located, she excavates a hollow and collects suitable material to build a nest in it, spending typically 5–10 h on the construction (e.g. Wood-Gush and Stolba, 1982; Jensen et al., 1993). During the first two days after birth, the sow will spend 90% of her time in the nest, only leaving the nest for brief foraging trips (Stangel and Jensen, 1991). The piglets spend these first days after birth resting in close contact with the sow and littermates, leaving the nest only to defecate (Stangel and Jensen, 1991). Remaining in the nest after birth serves several adaptive functions for the piglets: it facilitates the development of the mother-young bond (Jensen and Redbo, 1987), it reduces the chance of becoming separated from the sow or being detected by predators, and perhaps more importantly, gaining warmth (Fiala and Hurnik, 1983) and food from the udder. As other altricial mammals, piglets are born without fur or brown adipose tissue so their thermoregulatory capacity is poorly developed during the first days after birth (e.g. Berthon et al., 1994; Herpin et al., 2002). Although hypothermia is rarely recorded as cause of death in commercial pig herds, it might often be the primary

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0168-1591/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.applanim.2010.04.010

cause of starvation and crushing (reviewed by Edwards, 2002), as hypothermia renders the piglet less able to find a teat or avoid overlying by the sow (English, 1993). Heat from the udder will reduce the amount of energy needed to maintain body temperature and the intake of colostrum provides a valuable energy source for thermoregulation (Herpin et al., 1994), which in turn may increase the piglets' chances of survival. Piglets in semi-natural conditions start following the sow on small foraging trips from 4 days after birth, and the sow and litter rejoin the group around 10 days after farrowing (Newberry and Wood-Gush, 1988; Jensen, 1988).

Unlike the sow–piglet interactions observed in semi-natural conditions, where the sow leaves the piglets in the nest, modern farrowing systems are based on the principle that newborn piglets will leave the sow and enter a heated creep area. In this system, room temperature in the farrowing unit is kept within the sows' thermal comfort zone, around 20 °C, while a suitable microclimate (30–34 °C) to avoid hypothermia in piglets is provided in the creep area. However, numerous studies have found that young piglets prefer to huddle near the sow and littermates despite unfavourable thermal conditions in the sow area, instead of staying in the creep area during the first days after birth (e.g. Hrupka et al., 1998; Andersen et al., 2007; Moutsen et al., 2007; Vasdal et al., 2009). In fact, Hrupka et al. (2000) found that piglets were more attracted to an anesthetized piglet in a cold chamber than to an empty warm chamber, suggesting that the attraction to physical contact is stronger than the attraction to ambient heat. The piglets only start using the creep area to a substantial extent from day 3 after birth (e.g. Hrupka et al., 1998; Berg et al., 2006; Vasdal et al., 2009), which is the age when they would naturally start exploring the nest surroundings together with the sow (e.g. Stangel and Jensen, 1991).

Despite the piglets' motivation to lie close to the sow, many farmers' constructions and scientific studies have been aimed at increasing the attractiveness of the creep area while the use of the creep area in farrowing crates has been increased by: reducing temperature in the sow area (Zhou and Xin, 1999; Schormann and Hoy, 2006; Burri et al., 2009), adding a warm water bed in the creep area (Ziron and Hoy, 2003) or providing a simulated udder in the creep area (Lay et al., 1999; Toscano and Lay, 2005). Piglets in farrowing crates spend more time in the creep area than piglets in farrowing pens, possibly because the sow area is made less attractive by slatted floors, horizontal bars around the sow and reduced space (Blackshaw et al., 1994; Vasdal et al., 2009). Another reason for this difference might be the extra attraction of the sow area to piglets resulting from higher maternal motivation displayed by sows in farrowing pens showing more piglet-directed behaviour, higher responsiveness to piglet screams and increased nursing behaviour (e.g. Cronin et al., 1996; Arey and Sancha, 1996; Jarvis et al., 2005). Vasdal et al. (2010) found that 24-h-old piglets preferred 42 °C to other, lower infrared temperatures, and a thick layer of sawdust to both a foam mattress and a water mattress. Thus, it might be possible to increase the use of the creep area in loose-housed sows by combining a thick layer of sawdust with high infrared temperatures. However, although previous studies have shown that piglets in farrowing crates spend more time in the creep area than piglets in farrowing pens, a relationship between increased time spent in the creep area and piglet mortality has not yet been documented. This information would be important to the ongoing work of reducing piglet mortality in loose-housed sows.

The aim of this study was to investigate, firstly, whether improving the thermal comfort and softness of the creep area would increase time spent in the creep area during the first three days after birth, and secondly, whether this would affect early piglet mortality in loose-housed sows.

2. Material and methods

2.1. Experimental design

Loose-housed sows and their litters kept in individual farrowing pens were subjected to one of three creep area treatments during the first three days after farrowing (0–72 h); Control (CON); concrete floor in the creep area, bedding (BED); an insulated and soft bedding in the creep area and HUT; an insulated and soft bedding in the creep area, in addition to an extra wall, to increase the heat conserving capacity in the creep area. During four farrowing batches, a total of 46 sows were randomly allotted to one of the treatment pens: CON ($n = 17$), BED ($n = 15$) and HUT ($n = 14$) six days before expected farrowing.

2.2. Animals and housing

This experiment was conducted at the Pig Research Unit at the Norwegian University of Life Sciences. All sows were Yorkshire × Norwegian Landrace with parities ranging from 1 to 8 (mean ± S.E: 2.7 ± 0.2) and inseminated with semen from Duroc × Landrace boars. The sows were moved from the group housing gestation unit to the farrowing unit at day 110 post-insemination. The farrowing unit where the farrowing pens were located was insulated and mechanically ventilated and the air temperature was kept at 20 °C until farrowing, and then reduced to 16 °C.

Each farrowing pen measured 8.9 m^2 in total, and the sow area (part of the pen accessible to the sow) measured 7.0 m^2 with 3.7 m^2 slatted plastic floor (Fig. 1). The creep area measured 1.9 m^2, of which 1.0 m^2 was covered with a wooden ceiling. The creep area was separated from the sow area by a diagonal wall (2 m × 1 m) with a 20 cm gap along the bottom for piglets to enter. This diagonal wall was located 30 cm from the wooden ceiling in the creep area (Fig. 1). The solid floor in the sow area was covered by a 2 cm layer of sawdust in all three treatments, and all pens were cleaned out twice a day. The creep areas were maintained according to the treatment requirements.

The sows were fed to appetite with a standard lactation concentrate at 08:00 h and 14:00 h, in addition to 0.5 kg of roughage twice a day. From day 113 until farrowing the sows got 2.0 kg of straw daily for nest building. Lights were kept on for 24 h to allow video recording.

To avoid interference with the treatments, no assistance was given to newborn piglets at the time of farrowing.

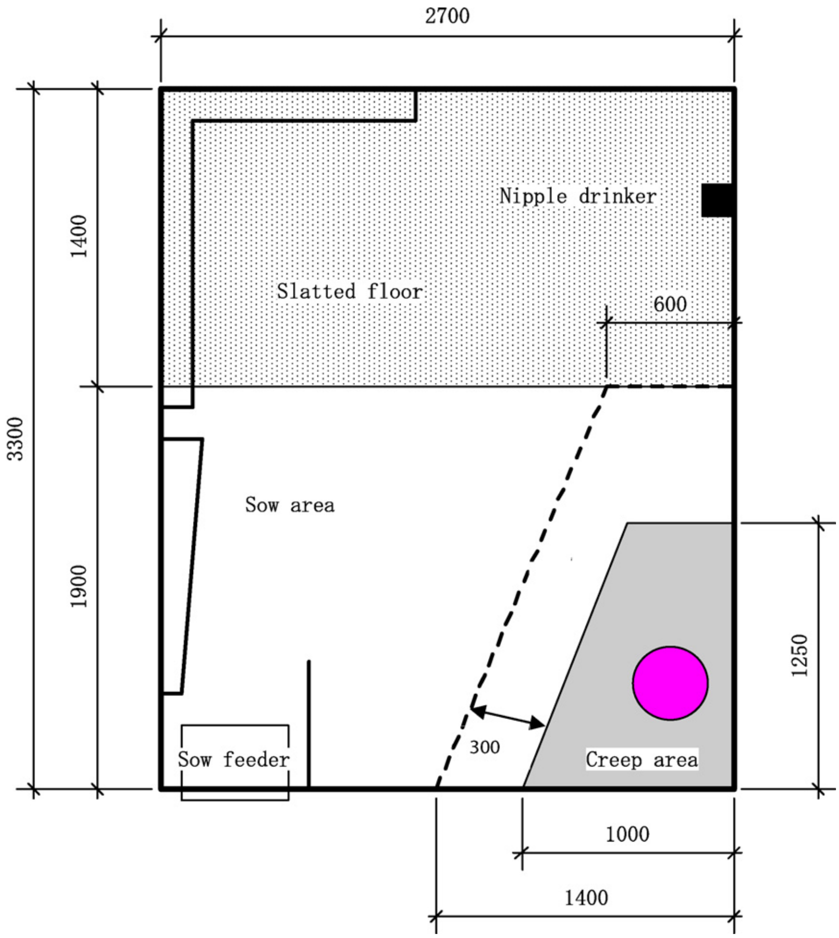

Fig. 1. The farrowing pen, creep area with heat lamp in the ceiling. All measures in mm.

During the first day after farrowing the piglets were individually weighed, ear tattooed, given iron injection and teeth grinded. Male piglets were castrated around day 5. Piglets in the largest litters were cross-fostered to the smaller litters between 12 h and 24 h after birth, so that no sow had more piglets than the number of functional teats. Piglets were cross-fostered equally within and between the treatments. Litter size in this study is thus number of live-born piglets fostered off + piglets fostered on from other sows.

Piglets not able to survive because of injuries or starvation were humanely euthanized by the staff and all dead piglets were subjected to a post mortem to determine cause of death. The dead piglets were categorized as stillborn (lungs sink in water), dead without milk in the stomach (lungs float, no milk in stomach), dead with milk in their stomach (lungs float, milk in stomach), crushed without milk in the stomach (physical signs of crushing, no milk in stomach) and crushed with milk (physical signs of crushing, milk in stomach). A physical sign of crushing included bruising to the body, cranial bone fractures, haemorrhages or crushed internal organs. In addition to the physical signs, the video recordings were used to document crushings.

2.3. The creep areas

All three creep area treatments had floors made of standard concrete, and a ceiling made of solid wood 65 cm above the floor. The creep areas were heated by a red infrared 250 W heat lamp mounted in the wooden ceiling. The infrared temperature was regulated by an infrared (IR) temperature controller (Model VE122S IR Controller, Veng Systems®, Roslev, Denmark) using an IR temperature sensor (Model VE181-50, Veng Systems®). The set-point infrared temperature in the creep area was 34 °C; however, as the heat lamp was unable to provide this temperature, the infrared temperature in the creep area remained at around 30 °C.

The different creep areas treatments were as follows:

CON: the concrete floor in the creep area was sprinkled with <100 g of sawdust, a similar amount to that used in commercial herds.
BED: Insulated and soft bedding: i.e. a thick layer of sawdust (7–10 cm) covered the entire concrete floor in the creep area.

Table 1
Piglet location (% of observations) in areas of the pen (means ± S.E).

	Treatment			Day after birth			Creep area features		Day after birth		Interactions treatment × day
	CON (n = 17)	BED (n = 15)	HUT (n = 14)	Day 0	Day 1	Day 2	$F_{2.88}$	P-value	$F_{2.88}$	P-value	P-value
In Creep	28.8 ± 4.5	30.4 ± 4.7	17.0 ± 5.0	17.0 ± 1.9	23.7 ± 3.2	38.3 ± 4.0	10.8	<0.001	6.8	<0.01	<0.05
Nursing	27.3 ± 2.0	24.8 ± 1.6	25.0 ± 2.3	37.8 ± 1.9	22.5 ± 1.3	16.2 ± 0.8	1.5	ns	50.8	<0.001	ns
Active sow area	10.3 ± 1.1	9.7 ± 0.7	12.4 ± 1.2	13.1 ± 0.9	11.4 ± 1.2	8.4 ± 0.6	1.9	ns	13.6	<0.01	<0.05
Resting alone	2.3 ± 0.7	3.6 ± 2.6	1.3 ± 0.4	1.5 ± 0.3	1.4 ± 0.4	1.8 ± 0.5	0.7	ns	0.7	ns	ns
Resting near sow	31.2 ± 2.9	31.3 ± 4.5	44.0 ± 4.2	30.1 ± 1.9	41.1 ± 2.8	35.1 ± 3.5	3.0	0.5	2.7	ns	<0.001

HUT: In addition to a thick layer of sawdust (7–10 cm) on the concrete floor, an extra diagonal wall with an entrance (20 cm × 40 cm) was added in the creep area to provide a better covered area without draught, with a more stable, higher infrared temperature. The infrared temperature in HUT was around 2 °C higher than in CON and BED treatments.

2.4. Behavioural observations

The sows were continuously video-recorded from 2 days before farrowing until 3 days after farrowing. A video camera was suspended over each pen and connected to a computer using the MSH video system (M.Shafro & Co., www.guard.lv). The behaviour of the piglets and their location in the pen was scored using instantaneous sampling every 10 min from 08:00 h to 14:00 h (6 h) and from 20:00 h to 02:00 h (6 h) at day 0 (0–24 h), day 1 (25–48 h) and day 2 (49–72 h), adding up to a total of 216 observations per litter. The video analysis of each litter began at 08:00 h on the morning after the farrowing was finished. These two periods were chosen due to the presumed high activity at 08:00–14:00 h, and presumed low activity at 20:00–02:00 h. In order to score the location of the piglets, the farrowing pen was divided into two zones: the creep area and the sow area (the rest of the pen).

The behaviour and location of piglets was scored using the following categories:

Number of piglets:

1. In the creep area.
2. Suckling (actively sucking on a teat).
3. Active in sow area (standing/walking/running/exploring etc.).
4. Piglet resting alone in sow area without body contact with sow or littermates.
5. Resting in contact with the sow or littermates.

2.5. Statistical methods

In the analysis, the litter was used as the statistical unit. The differences in piglet behaviour and location between treatments and days were analysed using a Glimmix model procedure in SAS software with Poisson distribution, including the following class variables: treatment (CON, BED, HUT), batch (1, 2, 3 and 4), days after farrowing (0, 1, 2) and sow parity (1–8). The interactions between treatment × batch and treatment × day were also included in the model. Sow was included as a random effect, and litter size was included as a continuous variable in the model. Piglet mortality and causes of mortality were analysed using a Genmod procedure in SAS with Poisson distribution including the following class variables and their interactions: treatment (CON, BED, HUT), batch (1, 2, 3, 4), days after farrowing (0, 1, 2) and sow parity (1–8), with litter size and birth weight included as a continuous variable. Due to the lack of normal distribution, relationships between piglet location and piglet mortality were analysed by a Spearman Rank correlation analysis.

3. Results

3.1. Piglet location in the pen

Piglets in the HUT treatment spent less time (% of observations) in the creep area than piglets in the CON and BED treatments ($F_{2.88}$ = 10.8, P < 0.001), while there was no difference in time spent (% of obs) in the creep area between the CON and BED treatment (Table 1). The number of piglets lying in the creep area increased in the first two days after farrowing ($F_{4.88}$ = 6.8; P < 0.01), and this increase was highest in the BED treatment ($F_{4.88}$ = 2.7; P < 0.05) (Fig. 2). There were large differences between litters within the same treatment in how much time they spent (% of obs) in the creep area; the litters ranged from 2% to 72% of the observations in all three treatments. Use of the creep area was not significantly affected by sow parity, birth weight or litter size.

A higher percentage of piglets rested near the sow in the HUT treatment than in the CON and BED treatment ($F_{2.88}$ = 3.0, P = 0.05) (Table 1). The percentage of piglets

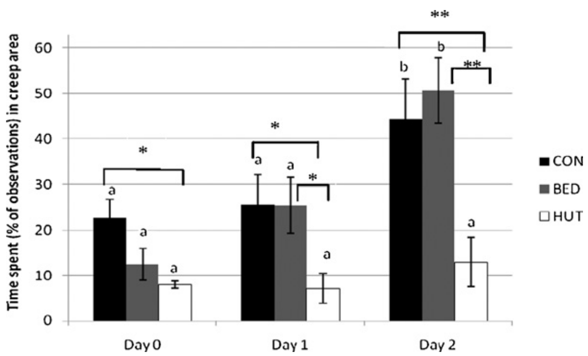

Fig. 2. Changes in time spent (% of observations) in creep area (mean ± S.E.) in the three treatments during the first three days after birth. Difference between days within treatment: a, b, c: P < 0.05. Difference within day between treatments: $^{*}P$ < 0.05, $^{**}P$ < 0.01.

Table 2
Piglet mortality (% of live born) in the three different creep areas (means ± S.E).

	Treatment			Creep area features	
	CON (n = 16)	BED (n = 14)	HUT (n = 12)	$\chi^2_{2,29}$	P-value
Litter size (number)	12.4 ± 0.4	13.0 ± 0.2	12.9 ± 0.4	0.0	ns
Stillborn*	6.2 ± 2.1	6.0 ± 2.4	5.3 ± 2.7	0.1	ns
Birth weight (kg)	1.6 ± 0.1	1.4 ± 0.1	1.5 ± 0.1	0.0	ns
Total mortality**	13.4 ± 3.9	12.9 ± 3.2	15.2 ± 3.3	2.9	ns
Dead other causes	8.1 ± 2.1	3.1 ± 1.2	9.9 ± 2.5	31.0	<0.01
Crushed total	5.2 ± 2.6	9.2 ± 2.9	8.2 ± 3.5	2.6	ns

* % of total born piglets.
** % of live-born piglets.

suckling, being active near the sow or resting alone were not affected by the treatments. During the first three days after birth the piglets decreased the time spent (% of obs) suckling ($F_{2.88}$ = 50.8; P < 0.001) and the time spent (% of obs) active in the sow area ($F_{2.88}$ = 13.6; P < 0.01).

Increased litter size reduced both the time the piglets spent (% of obs) resting alone ($F_{1.88}$ = 5.1, P < 0.05) and the time they spent (% of obs) resting near the sow ($F_{1.88}$ = 5.5, P < 0.05). Piglet location in the pen was affected by sow parity; litters of sows with parity 6 used the creep area more than any other parity ($F_{7.88}$ = 2.4, P < 0.05), while piglets of sows with parity 7 spent more time (% of obs) active near the sow ($F_{7.88}$ = 2.7, P < 0.05) than in the other parities. Sow had a significant effect on time spent (% of obs) in the creep area (t = 2.4, P < 0.05), time spent (% of obs) nursing (t = −5.8, P < 0.001) and time spent (% of obs) active in the sow area (t = −2.4, P < 0.05).

The percentage of piglets resting alone were higher in batch 1 than in the other batches ($F_{3.88}$ = 6.4, P < 0.05), while the percentage of piglets resting together with the sow were higher in batch 2 than in the other batches ($F_{3.88}$ = 5.5, P < 0.01). There was a significant interaction between batch and treatment on time spent (% of obs) active in the sow area ($F_{6.88}$ = 2.7, P < 0.05). However, there were no clear trends in the direction of these effects.

3.2. Piglet mortality

There were no significant differences in piglet mortality among the three treatments (Table 2). Neither sow parity, number of live-born piglets nor piglet birth weight differed significantly among the treatments. The overall piglet mortality in the study was 13.8 ± 3.4% of live born, of which 9.4 ± 1.9% died before receiving milk and 4.4 ± 1.5% died after receiving milk. There was no significant difference between the treatments in percentage of piglets dying before or after milk intake. There were no significant differences among the treatments in the percentage of piglets being crushed by the sow (Table 2). Fewer piglets died of causes other than crushing in the BED treatment than in the CON and HUT treatment ($\chi^2_{2,29}$ = 31.0, P < 0.01) (Table 2). In the CON treatment, piglets were crushed in 37% of the litters, while piglets died of other causes in 68% of the litters. These values were 50% of the litters (crushed) and 37% of the litters (other causes) in the BED treatment, and 31% of the litters (crushed) and 50% of the litters (other causes) in the HUT treatment, respectively. Piglet mortality was reduced from 9.5 ± 1.9% of the live born on day 0, to 6.5 ± 1.7% on day 1 and 3.0 ± 0.7% on day 2 (Fig. 3). Neither litter size nor birthweight had an effect on piglet mortality in this study.

The four batches did not differ in sow parity, litter size or birth weight. Batch 1 had a higher mortality rate ($\chi^2_{3,29}$ = 17.7, P < 0.01) and a higher percentage of stillborn piglets ($\chi^2_{3,29}$ = 9.5, P < 0.05) compared to the other three batches. There was no significant interaction between batch and treatment on piglet mortality. Piglet mortality was affected by sow parity; parity 3 (n = 6) and 5 (n = 5) had the highest piglet mortality, while parity 1 (n = 12) and 6 (n = 2) had the lowest piglet mortality ($\chi^2_{7,29}$ = 56.7, P < 0.001).

The total time spent (% of obs) in the creep area was not significantly related to piglet mortality in any of the treatments on day 0, day 1 or day 2. There was no relationship between mortality and time spent (% of obs) resting near the sow, resting alone or being active near the sow.

4. Discussion

Improving the thermal comfort and softness in the creep area neither increased the use of the creep area, nor was there any relationship between use of the creep area and piglet mortality. The creep area has long been considered an important part of the farrowing environment, providing the piglets with a suitable microclimate and physical protection from the sow, however, it appears difficult to attract

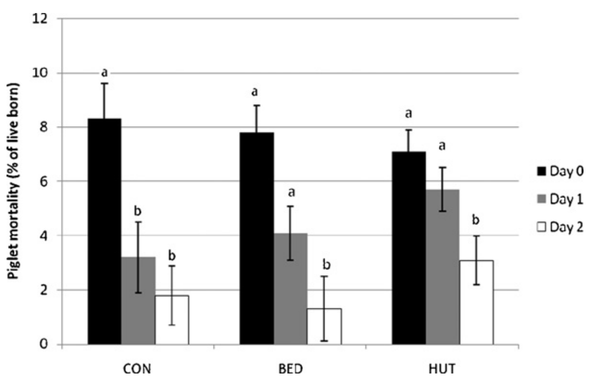

Fig. 3. Piglet mortality (mean ± S.E.) in the three treatments during the first three days after birth. Difference between days within treatment: a, b: P < 0.05.

newborn piglets away from the sow. The hut was actually least used of the three creep areas, opposite to what was predicted based on previous findings; that piglets are attracted to warm and soft areas when the sow is crated (e.g. Zhou and Xin, 1999; Schormann and Hoy, 2006; Burri et al., 2009) and in piglet preference tests (e.g. Hrupka et al., 2000; Vasdal et al., 2010). In total, the piglets in the present study spent less than a third of their time in the creep area, thus none of the three creep area treatments were able to attract the piglets away from the sow to a greater extent than reported in other studies of loose-housed sows (e.g. Berg et al., 2006; Vasdal et al., 2009). This can be explained by the fact that piglets are strongly motivated to lie close to the sow and litter mates early after birth regardless of the presence of a heated creep area (Hrupka et al., 1998; Andersen et al., 2007; Moutsen et al., 2007). Lying close to the sow after birth is a highly adaptive behaviour as staying close to the udder increases the piglets' chance of survival, and it can therefore be considered as a battle against biology to aim at attracting newborn piglets away from the sow. Earlier studies have suggested that variations in the sows' maternal behaviour may explain differences in the piglets' behaviour (e.g. Berg et al., 2006), but it is not clear if and how the sow encourages the piglets to use the creep area. From a biological point of view, improved maternal behaviour should in fact increase the piglets' attraction to the sow and would thus increase the time spent together with the sow, rather than the opposite.

In accordance with previous findings (e.g. Berg et al., 2006), there were large differences between litters in use of the creep area. However, there was no relationship between time spent in the creep area and piglet mortality. If increased use of the creep area was positive for piglet survival, differences in mortality should be expected between litters with high and low use of creep area. Vasdal et al. (2009) found that piglets in crates spent significantly more time in the creep area than piglets in pens, however, there were no differences in mortality between these environments (Pedersen et al., in preparation). These results suggest that the creep area is less important for piglet survival than previously thought. Contrary to previous studies (e.g. Weary et al., 1996), there was no relationship between time spent resting near the sow and piglet mortality in the present study. Thus it might be other factors, such as the physical state of the piglet like birthweight and body temperature (e.g. Pedersen et al., 2008) that explains early piglet mortality. Although mortality was not affected by birth weight in the present study, a majority of the piglets died before receiving milk, suggesting that starvation was a major predisposing factor for the mortality. Surprisingly, litter size had no clear effect on mortality in this study, contrary to previous findings (e.g. Andersen et al., in preparation; Weber et al., 2009; Pedersen et al., 2006). The negative effects of large litter sizes in the present study might have been camouflaged by the cross fostering, as the sows never had more piglets than functional teats.

In conclusion, offering a heated creep area with soft bedding did not increase time spent away from the sow, nor did it reduce piglet mortality. Quality of the creep area thus appears to have little impact on piglet survival.

Acknowledgements

This work was supported by the Norwegian Research Council. M. Melišová was supported by the Grant Agency of the Academy of Sciences of the Czech Republic (IAA603070801), by the Ministry of Agriculture in Czech Republic (MZE0002701404) and by EEA Norway grants. The authors would like to thank Dr. Gudrun Illmann for valuable comments on the manuscript.

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