EFFECTS OF STRESS DURING GESTATION AND ENRICHMENT DURING LACTATION ON THE BEHAVIOUR OF SOWS

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ABSTRACT

EFFECTS OF STRESS DURING GESTATION AND ENRICHMENT DURING LACTATION ON MATERNAL BEHAVIOUR OF SOWS

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Maternal behaviour was studied in sows to determine whether an enriched environment during lactation could modulate the effects of a stress during gestation. Sows were assigned to a social stress or a control treatment during gestation and housed in straw enriched pens or standard crates during lactation. A methodological study was first conducted to validate the use of accelerometers to automatically detect sow postures. Maternal behaviour was then evaluated using this new technology and behavioural observations. Stress in gestation resulted in decreased maternal responsiveness to recorded piglet squeals, less time spent with the udder exposed and decreased use of enrichment. The enriched housing resulted in sows performing more social contacts and exposing their udder more than sows in crates. Social stress in gestation may thus negatively impact maternal behaviour while an enriched housing during lactation allows more opportunity for its expression although it was not directly counteractive to the stress.

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Chapter 1: Introduction

Physical and social characteristics of the environment are important to consider when evaluating the impact of housing on the welfare of farm animals. In conventional swine production in Canada, sows are housed individually in stalls during practically all their productive life. In recent years however, societal and ethical concerns over the welfare of farm animals have put pressure on the farm animal industry to provide more welfare-friendly housing appropriate for the behavioural needs of animals. As a result, European countries such as the UK, Sweden, Switzerland, Denmark and the Netherlands have already banned gestation stalls for sows and the European Union has a ban effective in 2013, New Zealand in 2015 and Australia in 2017 (Council Directive 2001/88/EC; CSIRO, 2008; EU NAWAC, 2010). In North America, five American states have banned the use of gestation stalls and some large industry groups such as Smithfield Foods are also starting to phase them out in favour of group housing systems.

Group housing systems allow the sows to express highly motivated behaviours such as social interactions and foraging. However, this comes with its own set of problems since aggression between sows is a leading problem in terms of animal welfare. Excellent management and pen designs for group-housed sows are thus required to ensure that the welfare of these animals is superior to sows housed in crates.

Psychological and physiological stress occurs as a result of aggression between sows; stress hormones are released and some of them are able to bypass the foeto-placental barrier in pregnant sows and directly affect the offspring (Kranendonk et al., 2008). This phenomenon is termed prenatal stress and it has marked negative impacts on the behavioural and physiological development of piglets (Jarvis et al., 2006;

Kranendonk et al., 2008; Rutherford et al., 2009). In addition, stress during gestation could also influence the maternal behaviour of the dam. However, this has not been extensively studied in sows. Maternal behaviour in sows is in turn positively affected by a lactation environment that is adapted to their needs (Tuyttens, 2005).

The conventional housing of sows and piglets in farrowing crates during lactation is often criticized for severely restricting sow behaviour in the same manner as in gestation stalls, and preventing the performance of certain maternal behaviour (Cronin van Amerongen, 1991; Arey and Sancha, 1996). Loose housing systems are more difficult to manage as they often require more resources and surface area than farrowing crates, and carry a higher risk of piglet mortality by crushing (Barnett et al., 2001). Thus, only a few countries such as Sweden and Switzerland have so far banned the use of farrowing crates. However, similar productivity to crates can still be achieved with good management being the key to a successful use of farrowing pens.

The evaluation of maternal ability in sows must be based on an understanding of maternal behaviour and include observations of sow behaviour, postures and reactivity to relevant stimuli. Typically, live or video observations are used to observe behaviour; however, automated methods are being developed that have the potential to save time and be more reliable.

Chapter 2 will provide a review of the natural maternal behaviour of sows and the factors influencing it, with a particular focus on stress during gestation and enriched environments during lactation. Chapter 3 will conclude with a summary and the thesis objectives.

Chapter 2: Literature review

2.1 Maternal behaviour

2.1.1 The natural maternal behaviour of sows

In outdoor semi-natural settings, sow maternal behaviour is initiated one to two days before farrowing when the sow leaves the family group and seeks out a suitable nest site in a relatively protected area (Jensen, 1986; Jensen et al., 1987). The building of a nest by digging and using branches and other materials is triggered by hormonal changes prior to farrowing (Jensen, 1986; Jensen, 1988; Stolba and Wood-Gush, 1989; Widowski and Curtis, 1989). The nest and its isolated location serve to conceal the litter from potential predators, to protect the piglets from the cold, to reduce the risk of crushing and infection, to facilitate bonding and mutual recognition and to reduce the risk of alien piglets joining the litter (Jensen et al., 1987). During the first few hours after birth, it is also important for piglet survival that the sow stays relatively still in a lateral recumbent position to allow the piglets access to the udder, to keep them warm and to avoid crushing them (Pedersen et al., 2003). It is also essential for the sow to quickly respond to the piglets' squeals to prevent crushing piglets when lying down (Cronin and Smith, 1992; Weary et al., 1996b; Pedersen et al., 2003). The sow and piglets stay in close proximity to the nest for approximately ten days after which time they join other sows and their litters (Jensen, 1986).

Nursing in pigs is a complex behaviour that requires input from the sow as well as synchronized suckling from the piglets. The events triggering nursing can include sow movements or grunting, external stimuli such as the sounds of a nearby litter suckling or simply the piglets assembling at the udder (Fraser, 1980). Once at the udder, piglets start massaging teats and the sow's grunting rate increases to signal imminent milk ejection. At this time, piglets switch from massaging to sucking on a teat (Algers et al., 1990; Fraser, 1980). For the first day after farrowing, nursing bouts occur at short intervals to allow all piglets to ingest colostrum. Over the next couple of days, milk ejections then become more synchronized and shorter in duration as the transition is made from colostrum to milk (Algers and Uvnäs-Moberg, 2007). These nursing bouts occur approximately every 40–60 minutes and consist of the piglets assembling at the udder at specific teats, massaging the udder, ingesting milk during the short ejection period (5-20 s), followed by another period of massaging (Gill and Thompson, 1956; Ellendorf et al., 1982; Lewis and Hurnik, 1985). Early in lactation, more nursing bouts are terminated by the piglets while later in lactation, the sow terminates more bouts through postural changes (Jensen, 1986).

Bonding between the sow and the piglets occurs very early in lactation through nose-to-nose contacts and suckling (Jensen and Redbo, 1987; Petersen et al., 1990). Sow initiated nose-to-nose contacts with the piglets are rare on the day of farrowing (< 5 contacts/h) then increase in frequency during the first week (~ 10 contacts/h) before decreasing again to low levels at 2-3 weeks (< 5 contacts/h) (Jensen and Redbo, 1987; Blackshaw and Hagelsø, 1990; Stangel and Jensen, 1991). These contacts also include sniffing at the piglets as sows are capable of recognizing their litter starting at one day post-partum mainly through olfactory cues (Horrell and Hodgson, 1992). Piglet initiated nose-to-nose contacts with the sow also begin soon after birth (< 0.5 contact/h per piglet) and increase in frequency throughout the first few week of lactation (~ 1 contact/h per piglet) with about one third of all piglet-initiated contacts occurring around nursing

(Blackshaw and Hagelsø, 1990). Nose-to-nose contacts and vocalizations facilitate mutual recognition between the sow and the piglets, which is especially important in natural environments where the sow and piglets leave the nest within the first week. Once recognition is established, sows are then able to respond to piglets' signals of need, such as when they are trapped, hungry or isolated (Weary and Fraser, 1995).

2.1.2 Hormonal influences on maternal behaviour

The spontaneous onset of maternal behaviour in mammals is triggered by dramatic hormonal changes prior to and during parturition (Algers and Uvnäs-Moberg, 2007; Stolzenberg et al., 2010). A decrease in progesterone and an increase in prostaglandin are responsible for the rise in prolactin levels which triggers the onset of nest-building approximately 24 h before parturition (Jensen et al., 1987; Heckt et al., 1988; Widowski and Curtis, 1990; Algers and Uvnäs-Moberg, 2007). Nest-building then decreases approximately 4 h before farrowing which is likely due to the rise in oxytocin levels seen at this time (Castrén et al., 1993; Wischner et al., 2009). In rodents, oxytocin has been specifically linked with the onset of maternal behaviour; it is synthesized in the hypothalamus and released into peripheral circulation through the posterior pituitary gland as well as within the brain itself (Lim and Young, 2006). Oxytocin works as a neurotransmitter in the brain by acting on oxytocin receptors to regulate social and affiliative behaviour including the onset of maternal behaviour (Leckman and Herman, 2002; Lim and Young, 2006). Experimentally, the levels of oxytocin receptors have been demonstrated to increase in rodents as a result of high concentrations of estrogen and progesterone in late pregnancy followed by a drop in progesterone immediately prior to parturition (Amico et al., 1997). In sows, a similar pattern occurs with estrogen and progesterone levels being high at the end of gestation then dropping dramatically 48 h before parturition (Algers and Uvnäs-Moberg, 2007). During farrowing, high concentrations of oxytocin are released in pulses to facilitate uterine contractions and piglet expulsion (Gilbert et al., 1994; Lawrence et al., 1997; Algers and Uvnäs-Moberg, 2007). During lactation, as a result of udder massage by the piglets, the posterior pituitary gland releases oxytocin, which travels to the udder and increases intramammary pressure allowing for milk ejection (Valros et al., 2004; Algers and Uvnäs-Moberg, 2007). In addition, the increase in grunt rate of the sow prior to a milk ejection has been suggested to be linked with the release of oxytocin during udder massage (Algers et al., 1990). At parturition there is a prolactin surge, which is necessary for the initiation of lactation (Leckman and Herman, 2002; Devillers et al., 2004). As lactation becomes established, prolactin is released due to udder massage and is associated with increased milk production by redirecting energy to the udder rather than to fat storage (Algers et al., 1991; Valros et al., 2004; Algers and Uvnäs-Moberg, 2007). Hormonal changes are thus a major factor in influencing maternal behaviour such as nest building, farrowing, nursing and the natural weaning process.

2.1.3 Factors affecting maternal behaviour

The following factors have an impact on the maternal behaviour of mammals: genetics, stress, environment during gestation, environment during lactation, management practices, parity, litter size, nutritional status, endocrine profile, social effects, maternal stress, maternal anxiety, maternal depression, social support, maternal-foetal attachment and prior offspring care experience (Bales et al., 2002; Everett-Hincks and Dodds, 2007; Roussel et al., 2007; Shin et al., 2008; Baxton et al., 2010). Specifically in sows, it is known that previous experience, genetics and housing conditions influence maternal behaviour (Pajor et al., 2002; Thodberg et al., 2002a; Janczak et al., 2003; van den Brand et al., 2004; Grandinson, 2005; Jarvis et al., 2006; Algers and Uvnäs-Moberg, 2007; D'Eath et al., 2010). Compared to primiparous sows, sows with previous experience of piglet care show an earlier development of synchronised nursing and better control of nursing in late lactation (Thodberg et al., 2002b). Housing conditions can also physically alter the behaviour of lactating sows; for example, the constrictive nature of farrowing crates prevents the sow from performing some highly motivated maternal behaviour such as nest-building, whereas larger farrowing pens with enrichment allow the sow to perform a full range of maternal behaviour (Thodberg et al., 2002b; Wechsler and Weber, 2007). In terms of genetics, it is possible to select for more maternal sows as maternal responsiveness to a recorded piglet scream and to a human approach test was found to be genetically correlated with piglet survival (Grandinson et al., 2003). In addition, it has been shown that genetic selection for increased piglet birth weight and piglet survival was possible but that there was an interaction with the lactating environment in terms of changes in maternal behaviour (Roehe et al., 2009; Baxter et al., 2011). Furthermore, Lovendahl et al. (2005) found that aggressivity between sows during gestation was a heritable trait and that sows that were less aggressive showed stronger responses to handling of their own piglet. Therefore the authors concluded that selection against aggressivity would also be beneficial for maternal care. Another factor, stress during gestation, although not extensively studied in the sow, may impact maternal behaviour

(Jarvis et al., 2006). Many of these factors, such as age, genetics, health, the environment and stressful events, likely all interact and have an influence on the maternal behaviour of sows. Of particular interest to this thesis is the potential impact of a stress during gestation and the environmental conditions during lactation on sow maternal behaviour.

2.1.4 Measures of maternal behaviour in sows

Postural time budget, sow activity, nursing behaviour and social contacts with the piglets are often used to evaluate maternal ability in sows (Arey and Sancha, 1996; Pedersen et al., 2003; Hötzel et al., 2004; Jarvis et al., 2006). Since piglet welfare is often dependent on the sow's posture, behaviour such as standing, sitting and lying can be related to maternal instincts. In early lactation, lateral lying is particularly important to give piglets access to the udder and to keep them warm so sows spend upwards of 75 % of their time in this position (Pedersen et al., 2003). As lactation advances, lateral lying decreases while ventral lying, standing and sitting increase (Cronin et al., 1998; Weng et al., 2009; Lachance et al., 2010). The increase in time spent lying ventrally, sitting and standing is likely due in part to sows trying to prevent the piglets from being overly active at the udder (de Passillé et al., 1989; Valros et al., 2002; Hötzel et al., 2004; Cui et al., 2011). This is especially true if sows are housed in farrowing crates where they do not have the opportunity to physically get away from the piglets, whereas in natural conditions, sows usually begin to leave their piglets in between nursing bouts starting in the second week of lactation (Jensen, 1986).

When standing, lactating sows are in an active state and spend most of that time foraging and exploring their environment, especially if they are housed in a pen in the presence of an environmental enrichment (Arey and Sancha, 1996; Haskell et al., 1996). However, standing by lactating sows has to be interpreted differently according to stage of lactation and housing system. Given that in early lactation piglets require a near continuous access to the udder, standing by the sows may be associated with stress and more postural changes which increases the risk for piglet crushings (Wischner et al., 2009). In late lactation however, an increased time standing is likely linked with exploration and keeping the piglets from being overly active at the udder (de Passillé et al., 1989).

Because sitting is performed much less by sows in semi-natural rather than confined conditions, it has been suggested to be abnormal and possibly indicative of boredom (Dailey and McGlone, 1997; McGlone et al., 2004). Its role in regard to maternal ability is ambiguous. In early lactation, it has been found that sows that crushed more piglets also spent more time sitting and that the crushing occurred mostly when the sows changed postures from sitting to lying (McGlone and Morrow-Tesh, 1990; Cui et al., 2011). In late lactation, the behaviour may also be used to prevent piglets from suckling (Hötzel et al., 2004).

Maternal ability can also be evaluated through studying the sow's social interactions with her piglets (Arey, 1992). Nose-to-nose contacts facilitate bonding and mutual recognition, and are often performed when extensively-raised sows and litters reunite after leaving the nest (Petersen et al., 1990; Baxter et al., 2010). An increased performance of nosing piglets by sows has been linked to fewer accidental crushings (Andersen et al., 2005; Wischner et al., 2010). For example, Andersen et al. (2005) found that sows that had crushed piglets nosed their piglets significantly less when changing postures than those that had not crushed any piglets (2.5 ± 1.1 *vs.* 7.7 ± 1.6 contacts per postural change).

2.1.5 Maternal responsiveness tests

One way to quantify maternal ability is through observing the responses of sows to playbacks of recorded piglet squeals at different ages and in different conditions. The most commonly performed test of maternal responsiveness, the 'piglet crush test', simulates a piglet overlay situation as the sow lies down. The sow's postural changes and latency to respond to a playback of a recorded piglet distress call immediately after lying down are measured (Herskin et al., 1998; Held et al., 2006; Illmann et al., 2008). This test is performed in early lactation when most accidental piglet crushings occur (Andersen et al., 2005; Illmann et al., 2008). Some researchers tested the sows' own piglets, however it has been demonstrated that sows do not differentiate between their own or unfamiliar recorded piglet screams within the first few days of birth and they respond to playbacks of piglet screams significantly more than white noise (Weary et al., 1995; Weary et al., 1996a; Pajor et al., 1999). A good response, i.e. getting up quickly or changing posture to free the piglet, is considered indicative of good maternal behaviour (Hutson et al., 1992; Andersen et al., 2005). Thus, sows that score higher on that test should have fewer piglets that die due to crushing. However, there is a large variation in practice, with most studies reporting that less than 50 % of sows responded to the recorded piglet screams by changing posture, and results not necessarily predicting real crushing episodes (Weary et al., 1996c; Spinka et al., 2000; Pitts et al., 2002; Grandinson et al., 2003; Held et al., 2006; Chaloupkova et al., 2008; Illmann et al., 2008). In Illmann et al. (2008), sows were observed accidentally crushing their own piglets and responded to only 50 % of real piglet screams by changing postures. In Chaloupkova et al. (2008) however, 10 out of 17 sows trapped piglets and 80 % of the sows responded by postural changes. Thus the responsiveness of sows seems to be quite variable, and the validity of responsiveness tests may be dependent on other factors such as sow parity (Hutson et al., 1992; Held et al., 2005).

Another test used to assess sow's maternal ability is to examine their responsiveness to a separation from the piglets. This test is performed by isolating the sow in an acoustically- and visually-isolated test room and playing a recording of a squeal from an isolated piglet (Weary et al., 1996a). During and after the playback, the sow's latency to approach the speaker, nosing behaviour and movements are quantified (Pitts et al., 2002). Weary et al. (1996a) validated this test as an indicator of maternal care by demonstrating that sows show significantly more behavioural responses to calls of piglets versus birds and to calls of needy piglets versus thriving piglets.

A combination of observations of sow maternal behaviour such as postural budgets, activities and maternal responsiveness can be used to obtain an overall representation of the quality of maternal care.

2.2 Effects of stress during gestation

2.2.1 Sources of stress in gestating sows in commercial conditions

In North America, the large majority of gestating sows are housed individually in commercial gestation stalls that limit social interactions, restrict movement often to the point of injury, and lead to stereotyped and abnormal behaviour (McGlone et al., 2004;

Anil et al., 2005; Karlen et al., 2007). As welfare issues related to gestation stalls are revealed, group housing sows during gestation is becoming increasingly popular. Although group housing generally improves welfare, it can also lead to stress due to aggression upon introduction with unfamiliar sows (Spoolder et al., 2009). Indeed, when unfamiliar sows are introduced to one another, they engage in intense aggressive interactions until a relatively stable social hierarchy is established, which may take 1-2 days (McGlone et al., 2004; Spoolder et al., 2009; Chapinal et al., 2010). Given that gestating sows are usually on a restricted diet, aggression can also occur over feed competition if it is communally available, this fighting however, is less intense and shorter in duration but can occur every day (Spoolder et al., 2009). As a result of aggressive encounters, group housed sows exhibit increases in heart rate and salivary and plasma cortisol concentrations, physical injuries and weight loss (Marchant et al., 1995; Arey and Edwards, 1998; Meunier-Salaün et al., 2002; Jarvis et al., 2006). When comparing the heart rates of sows losing and winning an aggressive interaction, the heart rate of the sow that loses is typically greater (157 ± 8.7 *vs.* 128 ± 15.3 beats/minute) (Marchant et al. 1995). However, regardless of dominance rank, all sows involved in physical agonistic interactions show a sharp increase in delta cortisol concentration compared to unmixed sows (2.40 ± 0.71 *vs.* 0.09 ± 0.07 ng ml^{-1}) (Jarvis et al., 2006). Therefore, social stress is likely perceived as negative by the sows not only because of the physical injuries overt aggression can entail, but also due to the psychological stress subordinate sows are apt to experience (Arey and Edwards, 1998; Séguin et al., 2006).

2.2.2 Impact of stress in gestation on physiology and maternal behaviour

Pregnancy is characterized by an attenuation of the hypothalamic-pituitary-adrenal (HPA) axis response to stress, which protects the foetuses by reducing the normal response of circulating glucocorticoids (Hay et al., 2000; Lightman et al., 2001; Baker et al., 2008; Brunton et al., 2008; Slattery and Neumann, 2008; Brunton et al., 2010). Furthermore, there are major changes in the hormonal profile of sows during pregnancy (such as a flattened cortisol diurnal curve due to an increased concentration of cortisol during daylight hours) that alter the response to stress (Hay et al., 2000). Regardless, sows subjected to severe stressors during gestation do mount a behavioural and HPA axis stress response which can impact the offspring through prenatal stress effects (Arey and Edwards, 1998; Jarvis et al., 2006; Kranendonk et al., 2006a; Couret et al., 2009b). Stressful events during gestation have also been shown to negatively impact the maternal behaviour of rodents; for example, in mice, daily mild stressors during pregnancy (a combination of confinement, cage tilt, paired housing and reversed dark-light cycles) resulted in a marked reduction in the stressed dams' abilities to defend their pups (Pardon et al., 2000). In rats, gestational stress results in poorer maternal behaviour such as less arched-back nursing behaviour, less time spent gathering and grouping pups and increased anxiety-like behaviour compared to unstressed controls (Table 2.1). In Smith et al. (2004), pregnant rats were exposed to daily restraint stress during the second half of gestation. They were then tested during early lactation in a forced swim test and found to spend more time immobile than controls, which may be reflective of a depressed state. To further show the involvement of stress during gestation on maternal behaviour, Champagne and Meaney (2006) found that rats stressed during gestation through restraint

3 times a day for the last trimester had decreased levels of oxytocin receptor expression in their brain, which translated to poor maternal care (decreased licking and grooming of the pups).

Stress during gestation also likely impacts maternal behaviour through offspring mediated effects: offspring signalling may be changed due to the prenatal stress (Patin et al., 2002). Meek et al. (2001) investigated the impact of daily exposure to hot and bright lights and loud music during gestation and cross-fostering the offspring on maternal behaviour in mice. It was found that cross-fostering of stressed pups to unstressed mothers or vice-versa decreased maternal behaviour compared to stressed or unstressed dams raising their own pups. In a similar study using daily restraint stress during the last trimester in pregnant rats, Del Cerro et al. (2010) reported that cross-fostering affected pup retrieval and maternal care of the pups; there was a decrease in the retrieval rate in non-stressed mothers that reared stressed pups compared to unstressed dams rearing their own pups, which was likely due to decreased vocalizations emitted by the pups or to a higher activity by these pups. Stressed mothers that reared non-stressed pups showed increased physical contact and licking compared to stressed mothers that reared their own pups. These results may be important to take into account when studying prenatal stress in pigs as cross-fostering is a routine procedure used in farrowing rooms to equalize litter sizes.

In other species, the effect of stress during gestation on maternal behaviour has not been extensively investigated and only one study in pigs has specifically looked at the effect of stress during gestation on maternal behaviour during lactation. Jarvis et al. (2006) observed the maternal behaviour of sows (nest-building and postures) that had been socially stressed during mid- or late-gestation but found no treatment effect. However, observations only took place for the first 6 h post-partum, which may not have been long enough to detect differences since maternal behaviour changes over the course of lactation and the sow remains very passive in the first hours after birth (Jensen, 1986).

2.2.3 Impact of stress during gestation on the offspring

Prenatal stress is a term used to describe a stress experienced *in utero* that has an impact on offspring survival, behaviour and physiology postnatally (Braastad, 1998). Evolutionary speaking, prenatal stress allows the offspring to adapt to the environment into which it will be born (Kaiser and Sachser, 2005; Kranendonk et al., 2008; Couret et al., 2009a). For example, sexual development may be altered in terms of infantization or feminization of males and masculinization of females; sexual maturity may thus be retarded, which is beneficial in a highly competitive or unstable social environment (as reviewed by Kaiser and Sachser, 2005). However, in captive conditions, such adaptations may not be beneficial for the offspring as the post-partum environment likely does not contain the same stressors as the gestation environment (Braastad, 1998; Coe and Lubach, 2005).

In pigs, the consequences of prenatal stress range from HPA axis hyperactivation and increased pre-weaning mortality to disrupted behaviour patterns such as suppressed exploratory behaviour and increased fear and anxiety (Braastad, 1998; Haussmann et al 2000; Otten et al. 2001; Jarvis et al. 2006; Kranendonk et al. 2006b; Kranendonk et al., 2008). Gestation length, litter size, number of live-born piglets, and number of still-births are usually not affected by social stress or adrenocorticotropic hormone (ACTH) injections during gestation (Haussmann et al., 2000; Kanitz et al., 2003; Jarvis et al., 2006; Otten et al., 2007; Lay et al., 2008). In terms of physiological impact on the HPA axis, prenatal stress has been found to increase plasma and salivary cortisol concentrations and increase corticotropin-releasing hormone (CRH) concentrations in the hypothalamus (Haussmann et al., 2000; Jarvis et al., 2006), although Lay et al. (2008) found no impact on cortisol concentrations as a result of the stress of weaning. Furthermore, prenatal stress resulted in increased size and weight of the adrenal cortex of piglets (Haussmann et al., 2000; Jarvis et al., 2006; Couret et al., 2009a).

In terms of behavioural changes, in Jarvis et al. (2006), piglets from sows that were socially stressed during mid- or late-gestation performed more nosing, and more aggressive behaviour at weaning than unstressed controls. The authors suggested that this was likely indicative of a more difficult adaptation to separation from the sow and to a new environment. Furthermore, Kranendonk et al. (2006a) also reported negative effects of prenatal stress in mid-gestation on piglet behaviour, such as more vocalizations in an isolation test at 22 days of age, decreased play behaviour at weaning and more aggression and less nosing in a mixing test at 48 days of age. The divergent results in nosing behaviour in Jarvis et al. (2006) and Kranendonk et al. (2006a) are likely due to the social situations the piglets were in: in Jarvis et al. (2006), the piglets were weaned within their own litters (i.e., no mixing with unfamiliar piglets took place); on the other hand, the mixing test used by Kranendonk et al. (2006a) consisted of placing two unfamiliar piglet together in a new environment. Thus, a stress during gestation seems to negatively impact the behaviour of piglets only during stressful situations.

The timing of the stressor in gestation in pigs is relevant to the consequences on the young. For example, stress during early pregnancy may result in decreased litter sizes (Kongsted, 2004), during the second trimester in increased sensitivity of HPA axis re-programming (Otten et al., 2004; Jarvis et al., 2006), and during the last trimester in different effects on birth weight depending on the study (increased: Kanitz et al., 2006; Otten et al., 2007, no difference: Jarvis et al., 2006 and decreased: Kranendonk et al., 2006b). Given that in pigs, the maturation of the HPA axis *in utero* is completed by day 75 of gestation, it can be expected that greater effects on the HPA axis will be seen if prenatal stress occurs before the last trimester (Otten et al., 2004; Jarvis et al., 2006; Kapoor et al., 2008). A study by Brüssow et al. (2005) demonstrated that ACTH injections during mid- but not late-gestation results in a significant increase in cortisol concentrations in the umbilical vein of the treated foetuses compared to controls. However, when comparing behavioural effects on piglets postnatally, there was only a slightly increased negative impact of a stress during mid-compared to late-gestation (Jarvis et al., 2006; Kranendonk et al., 2006a). Jarvis et al. (2006) also observed the behaviour of the prenatally-stressed pigs at their own farrowing, and it was found that the gilts that were prenatally stressed in mid-gestation performed more postural changes at farrowing and tended to be more aggressive towards their piglets compared to the late-gestation stress and control groups. In terms of the physiological and behavioural effects in piglets, it seems that prenatal stress during mid gestation is more potent than a late gestation stress.

2.3 Experimental approaches to study stress during gestation

2.3.1 Methodologies to generate stress during gestation in sows

The gestational stress itself may have different effects on the sow and the piglets depending on the way the stressor is perceived by the sow. Researchers have stressed gestating sows with injections of ACTH and hydrocortisone acetate, by restraining them, by social stress and rough handling stress (Haussmann et al., 2000; Krandendonk et al., 2005; Jarvis et al., 2006; Kanitz et al., 2006; Lay et al., 2008). The injection of stress hormones is meant to create an identical physiological stress response in all sows regardless of perception (Kranendonk et al., 2005; Otten et al., 2007). However, the use of ACTH injections may cause differences in response because of individual variation in pituitary and adrenal gland reactivity (Kranendonk et al., 2005), whereas hydrocortisone acetate acts directly on the body without passing through other glands (Kranendonk et al., 2005). Nevertheless, these stressors are not what an animal experiences in its normal course of life. Therefore, actual psychological stressors may better represent stress experienced during gestation in commercial conditions (Jarvis et al., 2006). Ideally, stressors that are used experimentally should be relevant to the natural history of pigs. Thus, a restraint test using a nose sling may not be as relevant as a social stress which sows would normally encounter in the wild (Graves, 1984). As opposed to injections of ACTH, social stress activates the entire HPA axis (release of CRH, ACTH and then cortisol) as well as the sympathetic adrenomedullary nervous (SAM) system (Otten et al., 2002; Kaiser and Sachser, 2005).

2.3.2 Behavioural measures of stress

When experimentally inducing stress during gestation through mixing, there needs to be control so that all sows are stressed at a comparable level. To verify that the treatment actually does what it is intended to do, behavioural observations of the sows can be performed at mixing given that social contact between unfamiliar sows is expected to result in agonistic interactions until the establishment of a social order (Meese and Ewbank, 1973). In addition, scratch and lesion scores can be used as an indirect measure of aggression in group housed sows (Barnett et al., 1994 and 1996; Leeb et al., 2001). Since the amount of fighting decreases significantly within a few days of mixing, superficial injuries are generally only a short term consequence of mixing (Anil et al., 2005; Séguin et al., 2006; Karlen et al., 2007). Displacement from the feed source by another sow is also an indirect measure of stress in group-housed gestating sows since they are generally on a restricted diet (Jarvis et al., 2006; Spoolder et al., 2009). Stereotypic behaviour such as sham-chewing, bar biting and excessive drinking may also be indicative of gestational stress (Robert et al., 1993; Stewart et al., 2010). However, the link between stereotypic behaviour and stress in sows in not clear and would likely be a long term consequence of chronic stress rather than a direct effect of acute stress. In mice, there is some evidence to suggest that brain adaptations as a result of exposure to intense stress may be the basis for some occurrences of stereotyped behaviour (Cabib, 2006). Non-invasive measures of stress through behavioural observations can thus be used to get a relative measure of social stress in group-housed sows.

2.4 Maternal behaviour and housing conditions during lactation

During lactation, sows are typically housed in farrowing crates; these are barren pens with concrete or slatted flooring and metal bars around the sow to reduce the risk of piglet crushing. This environment prevents the sow from performing full rooting and nesting behaviour and the sow and the litter are also restricted in terms of environmental and social interactions (Cox and Cooper, 2001; McGlone et al., 2004). Alternative farrowing systems exist that provide the sow and piglets with a more complex environment. Get-away farrowing pens such as the Werribee system are enriched loose housing farrowing systems with two areas: a nesting area and a dunging area which is accessible to the sow only (Cronin et al., 2000). This system allows for more natural piglet-sow interactions as the sow can control the time spent with the piglets. The welfare of both the sow and the piglets is improved as reflected by increased post-weaning feed intake in piglets, increased feed intake and decreased weight loss in lactating sows, and the ability to perform highly motivated behaviour such as nest building, exploratory and rooting behaviour as well as increased opportunity for sow-piglet interactions (Pajor et al., 1999; Cronin et al., 2000; Weary et al., 2008).

In general, studies have found that sows housed in complex environments with rooting materials (such as straw) perform more maternal related behaviour than sows without rooting material or in crates (Thodberg et al., 1999; Hötzel et al., 2004). Straw by itself, whether added to a farrowing pen or crate is important in promoting maternal behaviour. Cronin and van Amerongen (1991) modified a farrowing crate by adding straw and a cover over the crate to simulate a completed nest. After farrowing was complete, the cover was removed and straw was added for all sows. Sows in the modified crate performed more nest-building behaviour (18.6 ± 3.25 *vs.* 9.6 ± 1.53 % of activity), initiated more social contacts with the piglets in the first three days (2.9 *vs.* 1.0 % of observation time daily) and had increased vocal responses to their piglets' screams in early lactation (2.09 *vs.* 0.48 – vocal response score (0 – none, 3 – strong)) compared to control sows in barren crates during farrowing. However, it could not be determined whether these effects were due to the straw, the cover or a combination of the two. In Thodberg et al. (1999), when comparing farrowing pens with sand or concrete and with or without straw, it was found that straw had the biggest impact on maternal behaviour with sows spending increased time rooting and nest building pre-farrowing than sows without straw (16.7 ± 1.1 *vs.* 13.4 ± 1.1 h) and performing fewer postural changes during farrowing (2.1 ± 0.6 *vs.* 4.9 ± 1.2). Another study comparing barren farrowing crates with farrowing pens both with or without straw found that the straw resulted in more suckling grunts directed towards the piglets to signal milk let-down on day 1 (4.2 *vs.* 2.1 % of observation time), more post-suckling grunts during the first week of lactation (1.2 *vs.* 0.7 % of observation time) and less sham-chewing than for sows without any straw during late lactation (1.1 *vs.* 2.6 % of observation time) (Cronin and Smith, 1992). However, during lactation, postural budgets were not affected by the provision of straw in these three studies (Cronin and van Amerongen, 1991; Cronin and Smith, 1992; Thodberg et al., 1999).

Given the physical restriction in a farrowing crate, surface area may have a bigger influence on postural changes than straw does. In Cronin and Smith (1992), when comparing farrowing crates to farrowing pens, it was found that during the first week of lactation, sows in pens spent less time sitting (0.7 *vs.* 2.1 % time), more time walking (1.1

vs. 0.6 %) and performed fewer piglet-directed aggressive acts (0.0 *vs.* 0.1) regardless of provision of straw. Furthermore, Jarvis et al. (2004) also found that regardless of the provision of straw, sows housed in pens compared to crates spent less time sitting (0.84 *vs.* 2.24 % time), performed more substrate directed exploratory behaviour (11.11 *vs.* 5.56 % time) and a higher number of social interactions (nosing) with their piglets (41 *vs.* 25.25) on the day of farrowing. However, an increase in the width of a farrowing crate alone (from 42.5 cm to 80 cm) was not successful in improving maternal behaviour (Harris and Gonyou, 1998).

The ability to move about and the provision of straw have been shown to be important to facilitate maternal care in sows, but another feature of farrowing pens that is likely important for maternal behaviour and welfare is the ability of the sow to get away from the piglets (Boe et al., 1991; Pajor et al., 1999). In Weary et al. (2002), sows were housed either in get-away pens where sows could mix with other sows starting at day 12 of lactation or in individual pens (both with straw). In terms of maternal behaviour, it was found that the frequency of nursing was lower for get-away sows compared to controls (23.5 *vs.* 29.25 nursings per day). This may result in easier weaning as the piglets would already be used to being away from the sow. Pedersen et al. (1998) investigated the impact of a get-away housing system with co-mingling of the piglets (piglets from different litters mixing together) and an individual pen (both without co-mingling) on the maternal behaviour of sows. As lactation progressed, there were less nursing bouts in the get-away pens with piglet co-mingling compared to the other treatments, which could facilitate weaning.

Thus, the combination of a large surface area, substrate availability and the opportunity to get away from the piglets, allows for a much greater expression of maternal behaviour compared to a barren farrowing crate environment.

2.5 Potential counteractive effects of environmental enrichment on the impact of stress during gestation

A number of studies with rats have demonstrated that post-natal experiences can reverse the negative effects of prenatal stress on pups. Environmental enrichment after weaning was found to reverse the effects of prenatal stress in terms of increased play behaviour, decreased physiological response to stress, decreased anxiety, increased learning ability and spatial memory (Chapillon et al., 2002; Morley-Fletcher et al., 2003; Qian et al., 2008; Yang et al., 2007). However, the impact of an enriched environment has not been investigated in dams that were stressed during gestation. But it is known that for women at risk of post-partum depression (for example women that experienced stress during pregnancy), a strong social support network and a stable environment decreases the risk of developing this condition and improves maternal ability (O'Hara, 2009). In pigs, it is possible that the positive impact of environmental enrichment during lactation on maternal behaviour may offset the potential negative effects of a stressor during gestation.

Table 2.1: Impact of stress during gestation on maternal behaviour in rats.

Authors	Stress	Licking	Sniffing	Nursing	Retrieving pups
Baker et al., 2008	Restraint	⇩	⇩	⇔	⇩
Bosch et al., 2007	Social & restraint	⇔	n/a	⇩	⇔
Brummelte and Galea, 2010	Cortisol injections	⇔	n/a	⇩	n/a
Del Cerro et al., 2010	Restraint	⇩	n/a	n/a	⇩
Patin et al., 2002	Cat	⇩	⇩	⇔	⇩
Smith et al., 2004	Restraint	⇔	n/a	⇩	⇩

⇩ decreased occurrence of behaviour compared to controls

⇔ no difference in occurrence of behaviour compared to controls

n/a: behaviour not measured in study

Chapter 3: Thesis aims and objectives

Stress during gestation is known to have a marked impact on the mother in the post-partum period in some mammals; however this has not been studied in sows. The first objective of this thesis was to determine the effects of a social stress during gestation on sow behaviour during lactation. Given that environmental enrichment favours the expression of maternal behaviour in sows, the second objective was to determine whether an enriched environment during lactation could counteract the eventual negative impact of a stress during gestation on maternal behaviour.

It was hypothesized that stress during gestation would negatively impact components of maternal behaviour and that the environmental enrichment would counteract these effects. Specifically, we hypothesized that sows that were stressed in gestation would spend more time lying ventrally, less time lying laterally, show fewer social interactions with their piglets and show a decreased responsiveness to playbacks of piglet vocalizations than sows that were not stressed during gestation. Furthermore, we hypothesized that the environmental enrichment would reverse these effects in the stressed sows to levels comparable to unstressed sows.

To verify this hypothesis, two studies have been completed. The first was a methodological study aimed to develop and validate a new method to automatically measure postures (standing, lying laterally, lying ventrally and sitting) in sows using accelerometers, in order to save time and improve the objectivity of measurements in further research. Results from this study are presented in chapter 4. The second study aimed to establish the impact of a social stress during mid gestation on sow behaviour in lactation and further, to determine the impact of an enriched environment during lactation on sows exposed to a social stress during gestation. Results from this second study are presented in the fifth chapter.

This research, although of a fundamental nature, could have important implications for the swine industry. As group housing of gestating sows will likely start becoming the norm, it is important to investigate potential ways to alleviate the competitive stress that may be imposed on the animals.

Chapter 4: Validation of accelerometers to automatically record sow postures and stepping behaviour.[1]

4.1 Abstract

Two studies were performed to develop and validate an automated method of detecting postures and stepping behaviour in sows. In the first study, two accelerometers were simultaneously tested on 23 multiparous sows to detect the following postures: standing, sitting, lying ventrally and lying laterally. First off, a data set from 11 sows was used to establish the methodology and algorithm to automatically detect postures, and a second set from 12 sows was used for validation purposes. Sows were housed in gestating stalls, pens, farrowing crates or farrowing pens with straw. One accelerometer was fastened to a hind leg and the other to the back of the sow (between shoulder blades). The data loggers recorded the acceleration on three axes every 5 s for 6 h; these data were then converted into degrees of tilt, which were used to discriminate between postures according to angles determined with the first data set. Based on video observations, sows spent an average time of 23.1 ± 0.1 % standing, 24.6 ± 0.2 % lying ventrally, 48.1 ± 0.3 % lying laterally and 4.2 ± 0.1 % sitting. Sensitivity values (the extent to which the accelerometers correctly detect each posture) for standing, lying ventrally, lying laterally and sitting were 100 ± 0.01 %, 94 ± 0.04 %, 91 ± 0.2 % and 50 ± 0.4 %, respectively. Specificity values (the extent to which the accelerometers correctly identify true negatives) were above 90 % for all postures. The results suggest that individual

[1] This chapter is based on: Ringgenberg, N., Bergeron, R., Devillers, N., 2010. Validation of accelerometers to automatically record sow postures and stepping behaviour. Appl. Anim. Behav. Sci. 128, 37-44.

calibration would have increased the performance of the accelerometers for identifying sitting. The second study was performed to validate the use of accelerometers for counting hind limb stepping behaviour around feeding in 10 sows. Animals were housed either in gestating stalls or in pens and had an accelerometer fastened to one rear leg. The data logger recorded the acceleration on the vertical axis 10 times per s for 30 min, starting at the time of feeding. The accelerometer data was compared to video observations and 1448 steps were assessed in total. The average sensitivity value was 95 ± 0.04 % with an error of 5 ± 0.03 %. In conclusion, accelerometers can be successfully used to detect postures and the number of hind limb steps in sows.

Keywords: accelerometer, posture, sows, steps, methods

4.2 Introduction

Postures are often examined to study the impact of environmental conditions and physiological state on the animal. For instance, in the farrowing environment, evaluating the time spent lying laterally and lying ventrally is useful to make inferences on maternal ability of sows. It is important for piglet survival in early lactation that the sow performs few postural changes to avoid crushing, and that she remains mostly in the lateral recumbent position to provide colostrum and warmth to the piglets (Jarvis et al., 1999; Pedersen et al., 2003; Wischner et al., 2009). In gestation, the determination of time budgets provides insights on the effect of housing conditions, feeding and social grouping on the welfare of individual sows. For example, time spent lying down may be used as a measure of gestating sow comfort to compare different housing systems (Li and Gonyou, 2007; Tuyttens et al., 2008), or as a measure of satiety (Bergeron et al., 2000). Assessing lameness in sows could also involve an analysis of postural time budgets since lame animals have more difficulty in lying down and their ability to change postures may be impacted (Bonde et al., 2004).

Postures are usually measured through live or video observation of the animals. This can be subjective, depending on the criteria used to define the various postures, and can lead to errors due to poor within- and between-observer reliabilities (Martin and Bateson, 2007). Moreover, live or video observation is very time-consuming. Small data loggers that measure acceleration on three axes may be a standardized, cheap and effective alternative. They have been used to measure gait and posture in human patients suffering from chronic pain (Paraschiv-Ionescu et al., 2004), lying and standing positions in dairy cattle (Ito et al., 2009; Trénel et al., 2009), daily activities in dogs (Hansen et al., 2007), grazing behaviour in goats (Moreau et al., 2009) and various types of activities in sows (Cornou and Lundbye-Christensen, 2008).

The validation studies of accelerometers in farm animals have shown excellent results in distinguishing between postures or activities very distinct from each other, such as lying and standing (Müller and Schrader, 2003; Munksgaard et al., 2006; McGowan et al., 2007). However, differentiating closely related activities (for instance, feeding and rooting) in sows, dairy cows and goats has proven more difficult (Cornou and Lundbye-Christensen, 2008; Martiskainen et al., 2009; Moreau et al., 2009).

Infrared sensors have also been used to automatically detect position changes in sows; however, they could only differentiate standing and lying postures (Mainau et al., 2009). In addition, such a system requires that sows be housed in stalls. The first aim of the present experiment was to develop an automatic method which could accurately detect postures in sows regardless of housing conditions. Two accelerometers were used simultaneously (one on the back and one on a hind leg) for best recognition efficiency of the following postures: standing, sitting, lying laterally and ventrally.

The early detection of lameness in sows is particularly important as severe lameness is a major cause of culling (NAHMS, 2006) and results in poor welfare. Accelerometers have been shown to be useful for the study of locomotion and lameness in cows and horses as lame animals will shift weight from one leg to another more frequently while standing (Ashley et al., 2005; Rushen et al., 2007; Leach et al., 2009). In sows, stepping with the hind legs while standing has not been researched extensively, although Jørgensen (2000) identified hind limb stepping and swaying as clinical signs of claw disorders. The detection of lameness in sows could therefore involve an analysis of weight shifting of the hind legs while the animal is standing still. The second aim of the present study was to validate the ability of accelerometers to accurately quantify the number of hind limb steps taken by a sow during a feeding episode. This method could eventually be used in studies of lameness and locomotion in sows.

4.3 Materials and methods

4.3.1 Animals, housing conditions and accelerometers

Thirty-three Yorkshire-Landrace sows were selected from the experimental herd at the AAFC Dairy and Swine R&D Centre. The sows were fed according to regular management practices (once a day in gestation and twice a day in lactation) and had *ad libitum* access to water from nipple drinkers. Animals were cared for according to the recommended code of practice (Agriculture and Agri-Food Canada, 1993) and in conformity with the guidelines of the Canadian Council on Animal Care (Canadian Council on Animal Care, 2009).

The study on the detection of postures required two data sets: the first one to develop a methodology and algorithm to automatically detect postures and the second data set for the validation. Eleven multiparous sows were selected for the first data set: nine gestating sows were housed on partially slatted concrete flooring in stalls (0.64 m x 2.10 m) (n = 5) or in individual pens (1.50 m × 2.40 m) (n = 4), and two lactating sows were housed on full metal slatted flooring in farrowing crates (0.68 m × 2.10 m). Twelve multiparous sows were selected for the validation study. They included two gestating sows housed together in a pen (2.40 m x 4.50 m), two non-gestating sows housed individually in pens (1.50 m × 2.40 m) and four non-gestating sows housed in stalls (0.64 m × 2.10 m) with partially slatted concrete flooring. In addition, two lactating sows were housed in standard farrowing crates (0.68 m × 2.10 m) on full metal slatted flooring and two lactating sows were housed in farrowing pens on straw (1.50 m × 4.20 m). Animals were of different parities, reproductive states and housed under different conditions to test the accelerometers in a variety of situations.

For the measurements of stepping behaviour, ten multiparous sows (gestating and non-gestating) were selected. They were individually housed on partially slatted concrete flooring in standard gestation stalls (0.64 m × 2.10 m; n = 7) or in individual pens (1.50 m × 2.40 m; n = 3).

Three-channel data loggers (58 mm × 33 mm × 23 mm, 18 g; Pendant G Acceleration Data Logger, Onset Computer Corporation, Pocasset, MA, USA) were tested. They had a measurement range of ± 3 *g*, an accuracy of ± 0.105 *g* and a memory of 21.8 KB for combined x-, y-, and z-axis readings. The accelerometers could be programmed to log at intervals ranging from 0.01 s to 18 h. Postures were measured at a logging interval of 5 s on three axes which allowed for a maximum recording duration of 32 h and steps were measured at a logging interval of 0.1 s on one axis which allowed for a maximum recording duration of 1h 50 min. The accelerometers were factory calibrated, but calibration was verified by measuring tilt at known times. They were also synchronized with video recordings. For programming and reading the accelerometers, a coupler, an optical base station with USB interface and the HOBOware Pro computer program (Onset Computer Corporation, Pocasset, MA, USA) were used. The data was transformed and analyzed with Microsoft Excel (Microsoft Corporation, Redmond, WA, USA).

4.3.2 Experimental setup for the detection of postures

Sow postures were detected using two accelerometers: one on a rear leg and one on the back of the sow. Data loggers were programmed to sample the acceleration on the three axes every 5 s for 6 h. An accelerometer was fastened to a rear leg by a customized pouch made of tough, waterproof fabric attached with Velcro® straps around the leg of the sow (Fig. 4.1a); it was inserted in the pouch on the inside of the leg such that the x-axis was parallel to the leg of the sow and pointing down. A layer of Vet wrap™ (CoFlex, Andover Coated Products Inc., Salisbury, MA, USA) was wrapped around the device to secure it (Fig. 4.1b). The other accelerometer was inserted in a pouch on the back of the sow such that the x-axis was pointing towards the rear end of the sow and the y-axis pointing towards the right side of the sow (Fig. 4.1c). This pouch was secured on a Velcro® patch that was glued (Kamar® Adhesive, Kamar Inc., Steamboat Springs, CO, USA) to the back of the sow just behind the shoulder blades. As an additional protection and to prevent the sow from rubbing the pouch off the back, an elastic bandage was wrapped around the girth of the sow just behind the shoulders (with care taken not to cover the udder) (Fig. 4.1d). The sows used in this study were accustomed to human interactions and manipulations; this resulted in a quick installation of the loggers (less than 5 min) on the sows without a negative response. Nonetheless, a habituation period of at least 4 h was allowed before the recordings. The data loggers were removed the next day, and only occasioned a slight redness of the skin on the back.

Concurrent to recordings of the data loggers, digital videos were taken of the sows. These recordings were used as a reference against which to validate the accelerometers. The video cameras (Panasonic WV-CP480, Panasonic, Mississauga, ON, Canada) were set up to provide a complete view of the sow and the pen (or stall). They were programmed to record at four frames per s, which was sufficient to accurately record the four types of postures. Standing, sitting, lying ventrally and lying laterally were defined, respectively, as an upright position with only the hooves in contact with the floor; a partly erect position with stretched front legs and the caudal end of the body touching the floor; lying on the abdomen with the front legs folded under the body; and lying on either side with all four legs visible (Lou and Hurnik, 1998). The videos were analyzed with specialized software (Omnicast, Genetec Inc., Montréal, QC, Canada) by one observer with a 5 s scan sampling method corresponding with the sampling from the accelerometers.

4.3.3 Experimental setup for the detection of stepping

The number of hind limb steps was measured for 30 min per sow starting at the time of feeding by programming the data loggers to sample acceleration signals every 0.1 s on the x-axis only. The accelerometers were attached to a rear leg as described above, approximately 30 min before feeding, and removed 1 to 2 h later.

Concurrent to the data loggers recording, videos were taken of the sows using the same cameras and recording system as above. The cameras were positioned to have a direct side view of the rear leg on which the accelerometer was attached. They were programmed to record at 15 frames per s, which was sufficient to precisely determine the start and end of each step. A step was defined as the sow lifting the hoof off the ground and putting it back down. The videos were analyzed continuously by one observer and the data were entered with a binary code (0 = no step is underway, 1 = a step is underway) every 0.1 s. This video data was used as a reference against which to validate the accelerometers.

4.3.4 Data processing and analysis for the detection of postures

The acceleration data recorded by the loggers were converted into degrees of tilt by the HOBOware Pro software. The tilts of the axes were measured relative to the ground and thus changed according to the posture of the sow. To determine which of the three axes could differentiate postures, the average angle of each axis at known postures was computed for the first set of sows (Fig. 4.2). The axes that differed the most individually for one posture were then chosen to detect it: the x-axis on the leg accelerometer (X_L) was used to predict standing, the y-axis on the back accelerometer

(Y_B) was used to predict lying laterally, and the x-axis on the back accelerometer (X_B), to predict sitting (Fig. 4.2). Lying ventrally was then predicted by elimination. The y-axis on the leg was not used because there were cases when the accelerometer pouch moved around the leg of the sow. In this study, lying laterally was detected as one posture although separation into lying laterally left and lying laterally right could have been performed easily (Fig. 4.2).

The video data were paired with the postures for the 6 h recording period at the corresponding time (every 5 s). Cut-off points were found for each angle to provide the best percentage of agreement between the video recordings and the accelerometer data from the first data set (Fig. 4.3). An algorithm was then created to automatically calculate the postures from the degrees of tilt of the x-axis on the leg first, followed by the x- and y-axis on the back accelerometer:

IF ($X_L \geq 130°$) THEN posture = standing

ELSE IF ($Y_B \leq 45°$ or $\geq 135°$) THEN posture = lying laterally

ELSE IF ($X_B \geq 113°$) THEN posture = sitting

ELSE posture = lying ventrally

In order to validate the use of accelerometer data and the algorithm, sensitivity and specificity values were calculated for the second data set for the four postures by using the video data as the reference. These calculations were performed with true and false positives (TP, FP) and true and false negatives (TN, FN) for each posture. Sensitivity measures the extent to which the algorithm correctly detects a posture. It is defined as the proportion of scans identified for each posture by the observer that are correctly detected by the algorithm (TP / [TP + FN]). Specificity measures the extent to which the algorithm does not detect a posture. For each posture it is defined as the proportion of scans that are identified as a different posture than the one detected by the observer and that have also been detected as a different posture by the algorithm (TN / [TN + FP]). In addition, a confusion matrix was computed to illustrate the percentage of cases that were correctly and incorrectly identified by the algorithm.

4.3.5 Data processing and analysis for the detection of stepping

The acceleration data on the x-axis were downloaded from the data loggers in the same manner as above. At a stand still, the x-axis of the accelerometer read 1*g* which is the static acceleration of gravity. But even when no steps were taken, there could be some oscillation of the readings if another leg was moved or weight was shifted. Therefore, two cut-off points had to be determined above and below which significant vertical acceleration occurred (the sow was actually lifting the foot off the floor). Through comparison with the video data, it was established that the upper limit would be 1.4 *g* and the lower limit 0.6 *g*.

Another algorithm was created to automatically count the number of steps from the acceleration data. The cut-off points determined whether a step was underway every 0.1 s: if the acceleration was below 0.6 *g* or above 1.4 *g*, then there was a step underway. These data were then cleaned to show only one step for a succession of positive points with a minimum of 0.3 s between two steps (Fig. 4.4).

In order to validate the ability of the accelerometers and the algorithm to accurately count the number of steps, the video data was once again used as the reference (± 0.2 s). True positives (steps detected both by the video observer and the algorithm), false positives (steps detected by the algorithm but not the video observer) and false negatives (steps detected by the video observer but not the algorithm) were calculated. The sensitivity was calculated as for postures (TP / [TP + FN]); it refers to the degree to which the steps recorded by the observer were correctly detected by the algorithm. The error was defined as the proportion of steps wrongly detected by the algorithm and calculated as false positives over the number of steps detected by the algorithm (FP / [TP + FP]). Three sows did not sit and one sow did not lie down laterally during the 6 h recording period; these sows were excluded from the statistical analysis for these postures alone.

4.4 Results

4.4.1 Detection of postures

The standing posture was a very robust measurement with a sensitivity value of 99.5 ± 0.01 % (mean ± SD) and a specificity of 99.7 ± 0.005 %. Lying ventrally and laterally had satisfactory levels of detection with sensitivity values of 93.9 ± 0.04 % and 91.4 ± 0.22 % and specificity values of 91.2 ± 0.19 % and 98.2 ± 0.02 %. The sensitivity values for lying ventrally and lying laterally specifically for sows housed in gestation crates were 96.3 ± 0.09 % and 69.4 ± 0.38 %, respectively, with specificity values of 74.2 ± 0.29 % and 97.9 ± 0.02 %. Compared to the other sows, they did not have enough surface area to lie in a full lateral recumbent position. The sows housed in gestation pens and farrowing crates and pens, on the other hand had more surface area to lie down laterally and this was reflected in higher sensitivity values, which were 94.1 ± 0.04 % and 99.7 ± 0.005 % for lying ventrally and laterally, respectively, with specificity values of

99.5 ± 0.01 % and 98.4 ± 0.02 %. The sensitivity value for the sitting posture in all housing conditions was considerably lower at 49.5 ± 0.41 % with a specificity of 99.8 ± 0.002 %. The percentage of time spent in each posture and the frequency of postural changes are presented in Table 4.1.

Table 4.2 shows the percentage of postures correctly classified, as well as which postures were detected instead of the correct one when errors were made. Among these, 61.6 % of sitting scans were misclassified as lying ventrally, 5.8 % of scans for lying ventrally were detected as lying laterally and 3.1 % of lying laterally scans were classified as lying ventrally. The poor classification of sitting is partly due to the high variability in the back angles of the sows while sitting (min: 85.7°, max: 128.7°, mean ± SD: 115.32° ± 5.93). In addition, one sow spent 27.98 % of the time sitting. However the angle of her back was above 113° in only 3 % of the cases; therefore, this sow was not detected as sitting for the majority of the time spent in that posture.

4.4.2 Detection of stepping

Based on the video observations, a total of 1448 steps occurred. Table 4.3 shows the number of steps detected by the algorithm and the observer. A total of 1453 steps were detected by the algorithm, 1377 of these were correctly classified (true positives), 76 steps were detected by the algorithm when there was not actually a step occurring (false positives) and 71 steps were not detected by the algorithm (false negative). The average sensitivity value was 95.1 ± 0.04 % (mean ± SD) with an error of 5.2 ± 0.04 %.

4.5 Discussion

4.5.1 Detection of postures

The methodology we developed to detect postures in sows using two accelerometers resulted in a good classification of standing, lying ventrally and laterally and a poor classification of sitting. Standing had the best detection out of all postures with a very high sensitivity, meaning that very few postures other than standing were classified as such. This is attributable to the large angle difference of the leg accelerometer x-axis between the standing posture and the other postures. This posture can thus be recognized very accurately using only one accelerometer on a hind leg. Standing behaviour detection with the same accelerometers has also been validated in dairy cows (Ito et al., 2009).

There was a good detection of lying ventrally and laterally, although they were mistaken for one another in some cases. This was likely due to housing conditions; in standard gestating stalls, the sows were sometimes observed lying in an intermediate position by leaning against the bars. In such cases, the sow's back angle may have been right on the cut-off point which resulted in the algorithm oscillating between both postures even though the sow was not moving. However, for sows housed in farrowing crates or in pens, the two postures were better differentiated.

The fourth posture evaluated, sitting, was not well detected by the algorithm. There were a high number of sitting events misclassified as lying ventrally. The axes on the back accelerometer for the sitting and lying ventrally posture differ by less than 20°. This inherently predicts the difficulty in differentiating these two postures. In addition, the occurrence of sitting was very low: 4.24 % of the time versus over 20 % for the other postures. This resulted in a low number of data points available for the detection of sitting. Furthermore, one sow spent more time sitting than all other sows combined. However, for the majority of the time spent in that posture, this sow was not detected as sitting as the angle of her back was below the cut-off point.

Another problem identified was the large individual variability between sows in the back angle while sitting which was likely related to factors such as leg and body length. Accordingly, some sows were outside the cut-off points and not detected as sitting when they actually were sitting and vice versa. To deal with this poor recognition of sitting, this posture could be pooled with lying ventrally as these two postures were the ones most often mistaken for one another. This could especially be useful in studies where the detection of sitting itself is not important. However, if the sitting posture is of interest, the algorithm would have to be calibrated to individual sows. Furthermore, the position of the accelerometers on the sows could also have been altered to give better results for the sitting posture. For example, installing an accelerometer on a front leg instead of the back may have given better results. However, this would create its own set of problems, such as the sow displacing it by attempting to chew it.

In addition to the poor detection of sitting, limitations in using accelerometers to detect postures in sows include the possibility that they may shift or fall off. For instance, sows in late lactation with piglets and group housed sows may be more at risk of having the loggers removed by the other pigs. Nonetheless, in this study, sows housed in pairs and lactating sows with their piglets (up to day 12 of lactation) were used and no difficulty related to the position of the loggers was encountered. Overall, the use of these data loggers to automatically detect the postures of sows is advantageous because it eliminates the need for video cameras and lighting at night and allows the detection of postures regardless of housing systems for up to 32 h.

The twelve experimental sows used in this study spent an average time of 23.11 % standing, 48.05 % lying laterally, 24.60 % lying ventrally and 4.24 % sitting. These results correspond with other studies on postures of sows using video recordings and live observation. In Harris et al. (2006), gilts in early gestation spent an average time over 24 h of 23.3 % standing, 66.3 % lying (laterally and ventrally) and 5.3 % sitting. Li and Gonyou (2007) found similar values for sows housed in gestation stalls of different widths. For example, sows housed in 65cm wide stalls spent an average time of 15.9 % standing, 60.67 % lying laterally, 20.33 % lying ventrally and 3.1 % sitting. The slight differences with our study may be attributable to our sample of sows which were of different reproductive states, to the different period of recording and different types of housing conditions. However, the purpose of the study was to validate that accelerometer measurements reflect the real behaviour of the sows, independently of the period of observation chosen and its duration.

4.5.2 Detection of stepping

There was a good recognition of steps during feeding episodes of the ten sows for the leg on which the accelerometer was fastened. All sows stood during the entire observation period, however, if a sitting or lying episode had occurred during the recording, this could have easily been detected with the acceleration signals. The 5.2 % error rate included false negatives which were partly due to sows taking small steps where they barely lifted their foot off the floor, thereby not creating enough vertical acceleration for the algorithm to detect it. Leg conformation which resulted in the accelerometer not being perfectly perpendicular to the ground may also have increased the detection of false negatives. False positives occurred when a step was fairly long and the time between two accelerations (below or above the cut-off points) was more than 0.3 s, in which case two steps were detected instead of one. Furthermore, the algorithm sometimes identified body shaking movement as a step. Despite the 30 min habituation period, three sows did shake their foot with the accelerometer during the recording; this leg shaking was recorded as one step by the observer and as two or more steps by the accelerometer.

A major limitation in using this accelerometer to measure the number of steps in sows is the short memory. For an exact measurement of steps at a logging interval of 0.1 s, the maximum recording period is only 110 min. To increase the recording time, the logging interval could be increased to 0.2 s; however, since some steps only have one reading outside the limits, the accuracy of detection would be decreased. An additional problem was that the data loggers were put onto the sows early in the morning before feeding. Most sows were fairly agitated at that time and as a result, it was sometimes difficult to install the loggers as they were kicking and moving about. Nevertheless, feeding time is the ideal period to measure the number of steps in individually housed gestating sows, as it ensures that all tested sows are in a similar situation. The use of accelerometers to detect steps could be further validated to measure locomotion in group housed sows.

4.6 Conclusion

To our knowledge, the present study is the first using two accelerometers simultaneously to automatically measure postures. The postures are determined by the position of the sow's leg and back and do not rely on a subjective assessment by an observer; it is thus a standardized method for postural differentiation. The accelerometer and the algorithm developed can be used to accurately detect standing, lying ventrally and lying laterally. Further work is needed to refine the recognition of sitting. Finally, the same accelerometers may be used to precisely detect the number of hind limb steps in individually housed sows around the time of feeding.

Acknowledgements

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Table 4.1: Postural time budgets for sows in gestation and lactation (in % of time)

		% of time				Frequency of
Housing	n	Standing	Lying ventrally	Lying laterally	Sitting	Postural changes
Gestation pen	4	22.91 ± 0.91	25.56 ± 1.07	51.49 ± 1.09	0.04 ± 0.07	9.00 ± 0.48
Gestation stall	4	28.10 ± 1.17	27.99 ± 1.16	35.11 ± 1.41	8.81 ± 0.90	10.25 ± 0.58
Farrowing pen	2	20.09 ± 0.26	11.25 ± 1.91	67.26 ± 1.16	1.44 ± 0.13	32.00 ± 0.84
Farrowing crate	2	16.53 ± 1.30	29.31 ± 2.99	47.84 ± 3.52	6.32 ± 1.30	25.00 ± 1.33

Table 4.2: Confusion matrix presenting the percentage of correctly recognized postures by the algorithm (in bold) and the percentage of errors classified by posture (% of scans).

	Video observation				
	Standing	Lying ventrally	Lying laterally	Sitting	Detected [a]
Algorithm					
Standing	**99.6 %**	0.2 %	0.2 %	0.4 %	8655
Lying ventrally	0.2 %	**93.5 %**	3.1 %	61.6 %	10301
Lying laterally	0.0 %	5.8 %	**96.7 %**	1.0 %	9676
Sitting	0.2 %	0.4 %	0.0 %	**37.0 %**	692
True positives[b]	8628	8658	10083	1955	29325

[a] total number of scans detected by the algorithm.
[b] total number of scans observed from the videos.

Table 4.3: Number of steps detected by the video observer and by the algorithm during 30 min periods after feeding (mean ± SEM). The sensitivity and error are also presented (n = 10).

Video	144.80 ± 0.75
Algorithm	145.30 ± 0.78
True positives	137.70 ± 0.76
False positives	7.60 ± 0.23
False negatives	7.10 ± 0.18
Sensitivity	94.31 ± 0.02 %
Error	5.28 ± 0.02 %

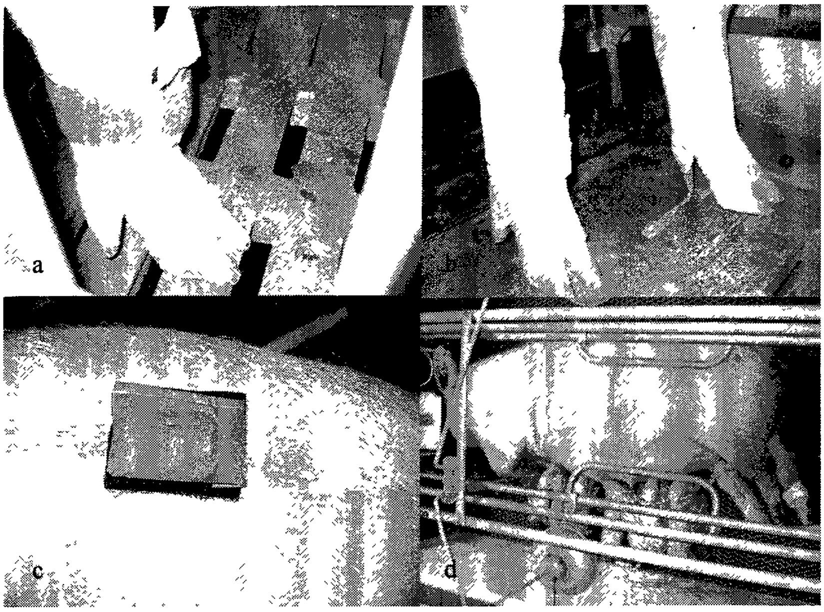

Figure 4.1: (a) Accelerometer pouch placed on the leg, (b) securing of the pouch with Vet wrap, (c) back accelerometer pouch, (d) sow lying laterally with the elastic bandage protecting the back accelerometer pouch.

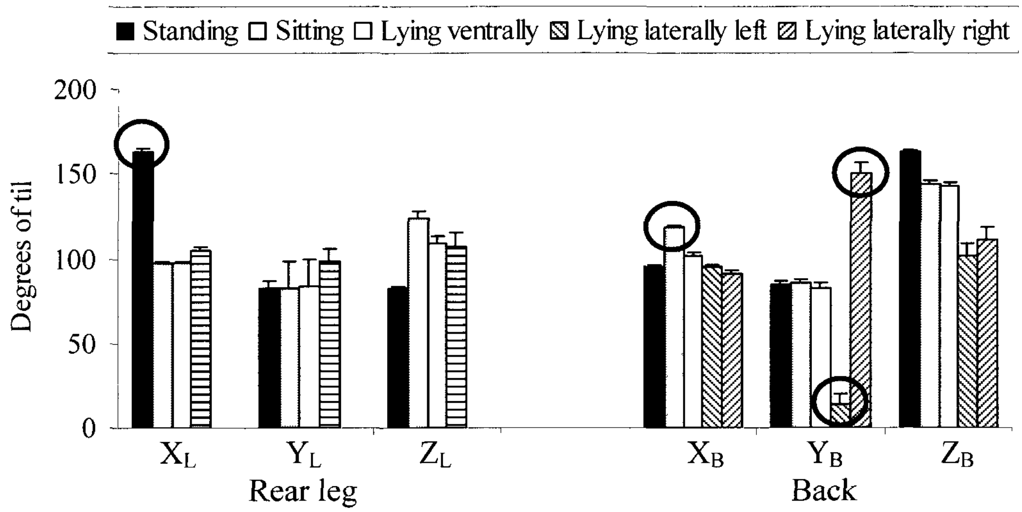

Figure 4.2: Average tilt values on each axis for five postures recorded by leg and back accelerometers on the 11 sows of the first data set (means ± SEM). Axes chosen to discriminate postures are circled. X_L, Y_L, and Z_L are the axes on the accelerometer of the rear leg and X_B, Y_B, and Z_B are the axes on the accelerometer on the back of the sow.

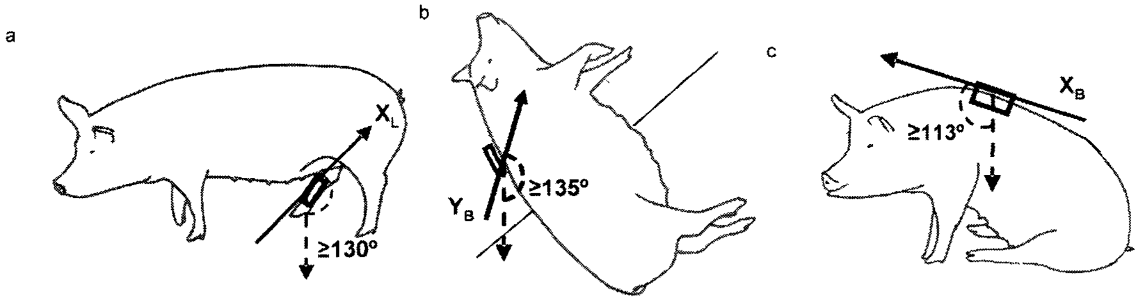

Figure 4.3: The tilt value of the axes relative to the position of the sow determines a) standing, if the tilt of the x-axis of the leg accelerometer (X_L) is greater than or equal to 130°, b) lying laterally, if the tilt of the y-axis of the back accelerometer (X_B) is greater than or equal to 135° (lying laterally left) or smaller than or equal to 45° (lying laterally right), c) sitting, if the tilt of the x-axis of the back accelerometer (X_B) is greater than or equal to 113°. Lying ventrally is then determined by a process of elimination.

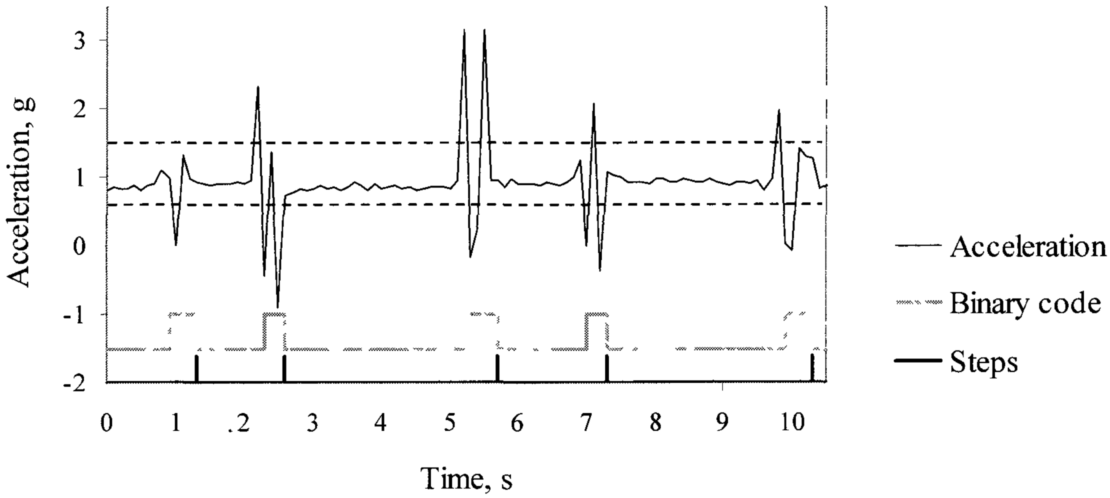

Figure 4.4: The typical acceleration pattern of hind leg steps of a sow, with sampling every 0.1 s by the data logger. The dotted horizontal lines correspond to the two cut-off points (1.4g and 0.6g) above and below which acceleration representing steps occurs. The binary code represents each time a step is underway and the black vertical lines (steps) are the output from the algorithm after cleaning the data.

Chapter 5: Impact of social stress during gestation and environmental enrichment during lactation on the behaviour of sows.[2]

5.1 Abstract

The impact of a social stress in gestation and an enriched pen in lactation on sow behaviour in lactation was studied in a 2 × 2 factorial experiment. At breeding, 41 sows were assigned to a social mixing stress treatment (T) during mid-gestation or a control group (C). During lactation, half of the T and C sows were housed in straw enriched pens (E) (1.57 m × 4.10 m) and the others in standard farrowing crates (S) (0.68 m × 2.10 m). The mixing stress consisted in introducing each T sow with two unfamiliar and larger sows twice for one week, from d 39-45 and 59-65 of gestation. Aggressive behaviour was observed and lesion scores were taken to confirm that a social stress occurred. During lactation, the responses of sows to piglet vocalization playbacks were observed on d 3 and 21. In addition, postural budgets of sows were automatically detected using accelerometers on d 5 and 19 of lactation. Sow-initiated social contacts with the piglets were observed continuously from video recordings on d 6 and 20 of lactation. Data were analyzed with a mixed models procedure. There were interactions between the mixing and housing treatments for the time spent standing on d 19 and for the time spent close to the speaker in the isolated piglet playback test. In terms of main effects, the mixing treatment had an impact on the response of sows to isolated piglet vocalisations with T sows showing longer latencies to respond vocally than C sows (16.25 ± 2.06 *vs.* 12.95 ± 1.27 s, $P = 0.035$). In early lactation, T sows spent more time lying ventrally than C sows (11.08 ± 1.41 *vs.* 7.13 ± 1.35 % of time, $P = 0.0072$). Furthermore, the social stress had

[2] This chapter has been prepared for submission to the journal of Applied Animal Behaviour Science.

an impact on the use of environmental enrichment, with T sows tending to spend less time in the nesting straw area of the pen than C sows (38.57 ± 8.36 *vs.* 58.37 ± 9.53 % time, P = 0.061). Housing also impacted maternal behaviour with E sows tending to spend more time lying ventrally than S sows (14.60 ± 1.38 *vs.* 20.93 ± 4.25 % time, P = 0.067) and tending to have more social contacts with their piglets than S sows in early lactation (28.44 ± 8.69 *vs.* 19.95 ± 8.90 contacts per 6 h, P = 0.058). In conclusion, the mixing stress during gestation had a slight negative impact on sow maternal behaviour, and while an enriched farrowing pen allowed for more opportunities to express maternal behaviour, it did not counteract the negative effects of gestation stress.

Keywords: stress in gestation, sow maternal behaviour, environmental enrichment, loose farrowing pen

5.2 Introduction

Gestating sows are increasingly housed in social groups rather than the conventional gestation stall, as has been legislated in European regulations (European Council Directive 2001/93/EC, 2001). This confers a number of welfare advantages such as the freedom to perform normal feeding and social behaviour as well as the opportunity to explore and exercise (Karlen et al., 2007; Chapinal et al., 2010). However, upon the formation of a new social group, sows frequently display overt physical aggression toward each other until a relative social ranking is established (Marchant et al. 1995; Arey and Edwards, 1998; Hoy and Bauer, 2005).

Stress resulting from aggression during gestation not only negatively affects the welfare of the sows, but it may also have a negative impact on the piglets' behavioural and hormonal responses to stress as well as their immune system (Jarvis et al., 2006; Otten et al., 2007; Couret et al., 2009a). For instance, piglets stressed prenatally showed increased aggression, more nosing and less play behaviour at weaning (Jarvis et al., 2006; Kranendonk et al., 2006a). Moreover, stress during gestation may have a negative impact on the maternal behaviour of sows, although such effects have not been found for the first six hours post-partum in Jarvis et al. (2006). In humans however, it is known that stress during pregnancy is a risk factor for post-partum depression and poor maternal care (O'Hara, 2009; Brummelte and Galea, 2010). This is also true in rodents with gestational stress resulting in increased anxiety-like behaviour and decreased maternal behaviour such as pup-directed licking and nursing (Baker et al., 2008; Brummelte and Galea, 2010).

On the other hand, the post-partum environment is important in terms of facilitating or preventing the performance of maternal behaviour. Conventional farrowing crates effectively prevent sows from crushing piglets by controlling the movements of the sow while lying down and changing posture; however, it is very constrictive in terms of allowing the performance of maternal behaviour (Arey and Sancha, 1996; Weary et al., 1996b). In contrast, an enriched farrowing pen lets the sow perform highly motivated nest-building behaviour and interact freely with the piglets, while providing increased opportunities to explore the environment and to move away from the litter (Csermely, 1994; Algers and Uvnäs-Moberg, 2007).

Enriched housing conditions during lactation have been shown to reverse the negative effects of prenatal stress in the offspring of rodent dams stressed during gestation (Morley-Fletcher et al., 2003; Yang et al., 2007; Qian et al., 2008). In pigs given that environmental enrichment during lactation improves maternal care, and that stress during gestation may reduce maternal behaviour, it may be possible to counteract the effects of a stress during gestation with an enriched environment in lactation. Therefore, the objectives of this study were two-fold: 1) to determine the impact of a social stress during mid gestation on components of maternal behaviour in sows, and 2) to study whether an enriched environment during lactation could counteract the effects of a social stress in gestation.

5.3 Materials and methods

5.3.1 Animals and production measures

Forty-one second parity Yorkshire-Landrace sows were selected from the experimental herd at the AAFC Dairy and Swine Research and Development Centre in Sherbrooke, QC. They were artificially inseminated with pooled semen from a group of Duroc boars after estrous synchronization with Regu-mate™ (Intervet Canada Inc., Whitby, ON, Canada). During gestation, the sows were housed in individual pens (1.50 m × 2.40 m) on partially slatted concrete flooring. They were fed a commercial diet for pregnant sows (12 % CP, 3107 kcal DE kg $^{-1}$ and 0.70 % lysine) once a day in the morning according to regular management practices and had *ad libitum* access to water from nipple drinkers. Animals were cared for according to the recommended code of practice (Agriculture and Agri-Food Canada, 1993) and in conformity with the guidelines of the Canadian Council on Animal Care (2009).

In order to equally distribute average body weights between treatment combinations, sows were assigned to the treatment in gestation according to their weight at breeding and then to the treatment in lactation according to their weight on d 104 of gestation (average weights: 228.83 ± 1.85 kg at breeding and 260.89 ± 2.00 kg on d 104). The two factors were (M) mixing treatment during gestation: social stress (T) *vs.* control (C), and (H) housing during lactation: standard farrowing crate (S) *vs.* enriched farrowing pen (E).

T sows (n = 20) were mixed twice, from d 39-45 and d 59-65 of gestation with two different pairs of sows. The social stress consisted in introducing the T sows individually into the home pen (2.40 m × 4.55 m, partially slatted concrete flooring) of two older gestating sows that were familiar with each other but unfamiliar to the T sows. These pairs of sows were also 10-20 kg heavier to increase their chance of becoming dominant over the T sow. Control sows (n = 21) remained undisturbed in their home pen (1.50 m × 2.40 m) during the entire gestation. All sows were weighed and their back-fat was measured ultrasonically at the last rib (Ultrascan 50, Alliance Medical Products Inc., Irvine, CA, USA) at breeding, on d 104 of gestation and on d 3 and 21 of lactation.

On d 104 of gestation, the sows were moved to the farrowing unit. They were allocated to one of two housing treatments: a standard farrowing crate (S) or an enriched farrowing pen (E). This resulted in 10 TE sows, 10 TS sows, 11 CE sows and 10 CS sows. Each farrowing room contained two enriched pens and two farrowing crates. The farrowing crate (space available to the sow: 0.68 m × 2.10 m) had slatted metal flooring underneath the sow, and plastic-coated expanded metal flooring in the piglet area on either side of the sow. The entire surface area available to the piglets was 1.60 m × 2.10 m. Two rubber mats and a water nipple for the piglets were present, as well as two ceramic heat lamps until d 3, at which time one of them was removed. The enriched pen (1.57 m × 4.10 m) consisted of two areas: a nesting area with straw and a dunging area with plastic-coated expanded metal flooring (Fig. 5.1). There was a 25 cm high wall in between the two areas to prevent the piglets from leaving the nesting area in the first few days after birth. Fresh straw was added and dung cleaned out of the pens daily. An average of 39.75 ± 1.81 kg of straw was used per sow during the 3 weeks of lactation.

From d 104 of gestation until farrowing, sows were fed two equal meals of a standard diet for lactating sows (16 % CP, 3370 kcal DE kg^{-1} and 0.94 % lysine) totalling 3.1 kg d^{-1}. On the day of farrowing, sows received 0.5 kg of this diet, and from d 1 of lactation until weaning, sows were fed the same diet *ad libitum* with fresh feed offered twice a day (at 7:30 and 15:00) and feed refusals weighed daily. Water was available *ad libitum*.

On d 1 of lactation (day of birth = d 0) litters were standardized to 12 piglets if necessary. No cross-fostering was done between litters. Iron injections and ear notching were also performed on d 1 of lactation on the piglets (no castration, tail or teeth trimming was performed). Piglets were weighed on d 1, 7, 14 and 21. No creep feed was distributed to piglets before weaning at d 21 and they did not have access to sow feed.

5.3.2 Behavioural measures in gestation

During the first day of each week of mixing (d 39 and 59 of gestation) the aggressive behaviour of the T sows and the resident sows was continuously observed for 6 h from the start of mixing (9:00 – 15:00) using digital video cameras (Panasonic WV-CP 480, Panasonic, Mississauga, ON, Canada) and specialised viewing software (Omnicast, Genetec Inc., Montréal, QC, Canada). Fights were defined as at least three consecutive aggressive interactions (bites, head-knocks and displacements) between two sows with less than 5 s between each interaction. Bullying was defined as at least three consecutive aggressive acts with less than 5 s between each act performed by one sow on another without retaliation. Individual aggressive acts were also recorded as well as the initiator and winner of each interaction (ethogram adapted from Mendl et al., 1992). In addition, the number of fresh scratches and lesion were recorded on T sows the morning before each social grouping, 24 h later and on the last day after removal of the T sows. Fresh scratches and wounds that were bright red and longer than 2 cm were counted on the entire body.

5.3.3 Measures of maternal behaviour

In the morning of the third day of lactation, a simulated piglet crush test was performed on the sows and videotaped with a mini digital video camcorder (Sony, DCR-HC52, Tokyo, Japan). Beforehand, a 1 min sequence of vocalizations from an unfamiliar 3-day-old piglet was obtained by gently squeezing it between the experimenter's hands and recorded with the sound analysis program Raven Pro 1.3 (Cornell Lab of Ornithology, Ithaca, NY, USA). In the enriched farrowing pens, the speaker was placed inside the piglet creep area (Fig. 5.1) and at the rear right or left hand side of the farrowing crates (alternation of sides for each treatment). For each sow, the test was carried out as follows: the experimenter made the sow stand up if not already standing and then quietly waited in the room and out of the view of the sow, as the sow was in the process of lying down; the recorded piglet squeals were played as the hind quarters touched the ground. The recording was played at a volume (70-80 dB), comparable to spontaneous piglet distress vocalizations, until the sow stood up or until 1 min had elapsed. The latency to respond was measured as well as the response of the sow (0 = no response, 1 = turning head towards sound, changing lying posture or sitting, 2 = standing up) (adapted from Pitts et al., 2002; Grandinson et al., 2003).

Video recordings of sows and their litters were taken on d 6 and 20 of lactation from 12:00 until 18:00 using the video equipment described above. When viewing these video recordings, all tactile contacts initiated by the sow were continuously observed. A contact was defined as the sow touching a piglet with the snout. The location of the contact (for E sows: nesting or dunging area), the activity of the sow (nursing, resting or active) and the timing of the contact (whether the contact occurred during a nursing episode, during the 5 min prior to the beginning of a nursing, during the 5 min after a nursing had ended or in between nursing events) were noted. A nursing was defined as starting when more than 50 % of the piglets were active at the udder and ending when less than 50 % of the piglets were active at the udder for at least 60 s (Valros et al., 2004). A sow was considered as active when standing or sitting and as resting when lying without nursing.

On d 5 and 19 of lactation, the postures of the sows were automatically recorded for 24 h from 06:00 using two three-channel accelerometers (Pendant G Acceleration Data Logger, Onset Computer Corporation, Pocasset, MA, USA). One accelerometer was fastened onto the back of the sow and one to a hind leg to determine whether the sow was standing, sitting, lying laterally or lying ventrally (validated in Ringgenberg et al., 2010). The postures were recorded every 5 s and the percentage of scans in each posture was calculated to estimate the percentage of time spent in each posture. In addition, for the sows housed in the enriched pens, a 24 h video recording was used to determine the location of the sow in the nesting or the dunging area (all occurrences) for the same period.

On the day of weaning, an isolated piglet playback test was performed. The sow was walked down a hallway into an acoustically and visually isolated test pen (1.90 m × 3.60 m) that was divided into 6 equal rectangular areas with lines on the floor (0.95 m × 1.20 m). The sow was left undisturbed for 20 min to habituate to the new environment. The test started with the playback (at 70-80 dB, comparable to spontaneous piglet isolation calls) of a 1-min recording of grunts from a 21 day old unfamiliar isolated piglet, which was followed by 2 min of silence. The speaker was placed outside the corner of the pen opposite to the door. The sow was videotaped with a mini DV camcorder (Sony, DCR-HC52, Tokyo, Japan) and her vocalizations were recorded with the sound analysis program Raven Pro 1.3. The latency to the first vocalization and the frequency of all vocalizations were measured during the two phases of the test (phase 1: 1 min playback and phase 2: 2 min silence). The parameters measured included: latency to first movement (measured as first line crossed), total number of lines crossed with both front legs, latency before entering speaker zone, time in the speaker zone and escape attempts (adapted from Weary et al., 1996a). The sow was considered in the speaker zone when both her front legs and head were in the square in front of the speaker. The test pen was thoroughly cleaned after each test.

5.3.4 Statistical analysis

All statistical analyses were performed using the Statistical Analysis System Software (SAS Institute, Inc. 2003). Data were analyzed as a 2×2 factorial design with mixing treatment in gestation (M) and housing in lactation (H) as the two fixed factors. The 2-way interaction $M \times H$ was included in the model and the sow within treatments was used as a random effect. The experimental unit was the sow. For data that was not normally distributed (latency for first movement and latency to enter the speaker zone in the isolation test), a logarithmic or a square root transformation of the dependent variables was used. For the simulated piglet crush test, a logistic analysis was performed on the response of the sow to the test. All other behavioural data and the performance data were analysed using the Generalized Linear Mixed Models procedure of SAS with repeated measures analyses. For the variables related to T sows in gestation (scratches and aggressive behaviour), only descriptive statistics were conducted.

5.4 Results

5.4.1 Immediate effects of social stress in gestation on the sows

The social grouping led to intense aggressive encounters between T sows and the pairs of resident larger sows (Table 5.1). These aggressive encounters occasioned superficial scratches and lesions that increased throughout each week of grouping (Table 5.2). When counting the number of aggressive interactions initiated and won by individual sows, five T sows appeared to be dominant during the first mix (the sow initiated and won more than 50 % of aggressive behaviour for the 3 categories). However, during the second mix, only one of those sows retained a dominant status. Given that C sows remained in their home pens undisturbed, it is assumed that they did not experience stress during gestation.

5.4.2 Production data

On d 1 of gestation, S sows tended to be heavier than E sows (232.15 ± 2.75 kg *vs*. 225.67 ± 2.34 kg respectively, P = 0.071) although this difference was no longer present on d 104 of gestation (263.33 ± 2.76 kg *vs*. 258.57 ± 2.87 kg respectively, P = 0.23). On d 3 of lactation, S sows were again heavier than E sows (271.65 ± 3.91 kg *vs*. 254.93 ± 3.03 kg respectively, $P = 0.001$) and the difference was still significant on d 21 of lactation (251.18 ± 4.05 kg *vs*. 234.81 ± 3.75 kg respectively, $P = 0.0034$). S sows also consumed more feed than E sows during lactation (6.70 ± 0.21 kg d $^{-1}$ *vs*. 5.47 ± 0.21 kg d $^{-1}$ respectively, $P < 0.001$). However, the differences in weight and feed consumption did not affect the weaning to oestrus interval ($P = 0.072$), which was 4.84 ± 0.12 d for all sows. In addition there was no treatment effect on back fat with sows having an average back fat thickness of 22.51 ± 0.44 mm on d 104 of gestation ($P = 0.32$), 20.85 ± 0.54 mm on d 3 of lactation ($P = 0.49$) and 18.4 ± 0.49 mm on d 21 of lactation ($P = 0.66$).

In terms of piglet performance, the only difference between treatments was a tendency for higher mortality due to crushing in E sows compared to S sows (1.1 ± 0.30

piglets per sow *vs.* 0.4 ± 0.17 piglets per sow respectively, P = 0.059). Overall, with all treatments combined, there were 14.98 ± 0.52 total piglets born, 13.56 ± 0.44 live-born piglets and 10.51 ± 0.21 weaned piglets. In addition there were no treatment effects for birth weight (1.68 ± 0.02 kg, P = 0.64) or average daily gain between birth and weaning (0.30 ± 0.003 kg day^{-1}, P = 0.69).

5.4.3 Maternal responsiveness tests

The response rate for the simulated piglet crush test on d 3 of lactation was low, with 18 out of 41 sows not responding (response = 0). Eight sows responded by changing lying posture or sitting up (response = 1) and 15 sows responded by standing up (response = 2). There were no treatment effects for the response to the test (P = 0.79) or the latency to respond (Table 5.3). However, of the 15 sows that did respond by standing up (response = 2), the latency to respond tended to be affected by treatment in gestation with T sows taking longer to respond than C sows (24.75 ± 4.60 s and 11.29 ± 4.96 s respectively, P = 0.072).

During the one-min playback period (phase 1) of the isolated piglet playback test, there was an effect of treatment in gestation, with C sows vocalizing sooner than T sows (11.86 ± 1.24 s *vs.* 17.11 ± 1.24 s, P = 0.035) (Table 5.3). During phase 1, when looking at the main effects, the social stress treatment tended to decrease the latency to first movement compared to the control treatment in the standard housed sows (P = 0.082), whereas there was no effect of the social stress on the first movement in enriched sows (P = 0.34). There was also a tendency for an interaction between treatments (P = 0.059) for the latency to first movement (Fig. 5.2). Within the group of sows stressed during gestation, the enriched farrowing pen increased the latency to first movement compared to the standard crates (P = 0.0018), but there was no effect of enrichment in C sows (P = 0.79).

For the total time spent in the speaker zone, there were interactions between treatments for both phases (phase 1: P = 0.002, phase 2: P = 0.0002; Fig. 5.2). Within the group of sows housed in enriched pens, the stress in gestation increased the time spent in the speaker zone compared to the control treatment (phase 1: P = 0.076, phase 2: P = 0.0003; Fig. 5.2). For the sows housed in standard farrowing crates, the social stress tended to decrease the time spent in the speaker zone compared to the control treatment for phase 2 (P = 0.072), although there was no impact in phase 1 (P = 0.12; Fig. 5.2). In both phases, for the sows that were not stressed during gestation (C sows), the standard farrowing crate resulted in increased time spent in the speaker zone (phase 1: P = 0.0086, phase 2: P = 0.0078; Fig. 5.2). And lastly, for the sows that were socially stressed during gestation, the enriched farrowing pen increased the time spent in the speaker zone for phase 2 (P = 0.0043), but there was no difference for phase 1 (P = 0.50).

5.4.4 Sow postures and location

On d 5, T sows spent more time lying ventrally than C sows (P = 0.0072; Table 5.4). On d 19, E sows tended to spend less time lying ventrally (P = 0.067) and sitting (P = 0.074) and more time lying laterally (P = 0.056) than S sows (Table 5.4). There was an interaction between treatments for the time spent standing on d 19 (P = 0.001). When looking at separate effects of each treatment within the interaction, for enriched sows, the social stress treatment increased the time spent standing compared to controls (P =

0.035), whereas the social stress had an opposite effect in standard housed sows (P = 0.0065). In addition, for treated sows, there was an effect of housing, with enriched sows spending more time standing than standard housed sows (P = 0.0009).

In the enriched pens only, on d 19, sows changed location from the dunging area to the nesting area more often than on d 5 (14.70 ± 1.39 location changes *vs*. 10.83 ± 1.73 location changes, P = 0.023; Table 5.5). In addition, sows tended to spend more time in the nesting area on d 5 than on d 19 (60.20 ± 10.19 % *vs*. 36.75 ± 7.69 % time, P = 0.061; Table 5.4). On d 19, the stress treatment during gestation impacted the total time in the nesting area (P = 0.018). T sows spent less time lying down ventrally (P = 0.028) and laterally (P = 0.032) in the nesting area than C sows (Table 5.5). In addition on d 20, T sows nursed less in the nesting area than C sows (24.89 ± 11.31 % *vs*. 64.83 ± 24.88 % time, respectively, P = 0.019).

5.4.5 Social contacts between the sow and the piglets

T sows tended to exhibit a higher number of social contacts with their piglets in late lactation during the post-nursing period compared to C sows (6.70 ± 1.05 *vs*. 4.11 ± 1.05, P = 0.085; Table 5.6). In terms of housing effects, during the pre-nursing period, E sows initiated significantly more contacts compared to S sows on d 6 (6.35 ± 0.83 *vs*. 2.95 ± 0.83, P = 0.0056). During resting periods, there was a tendency for E sows to initiate more contact than S sows on d 20 (6.61 ± 1.26 *vs*. 3.05 ± 1.29, P = 0.056; Table 5.6).

5.5 Discussion

In this study, we tested the impact of a social stress during mid gestation and the potential compensatory effect of an enriched farrowing environment on the behaviour of sows during lactation. The social stress was shown to have a slight negative impact on maternal behaviour; stressed sows spent more time lying ventrally in early lactation, while in late lactation, they spent a lower percentage of time in the nesting area. They tended to stand up later in response to the simulated piglet crush test and took longer to respond vocally to isolated piglet playback grunts. However, the enriched environment during lactation failed to counteract these effects directly even though it had a positive influence on maternal behaviour. Indeed, whether or not they had been mixed during gestation, enriched sows tended to display more social contacts with the piglets in early lactation, and tended to spend less time lying ventrally and sitting and more time lying laterally in late lactation.

5.5.1 Immediate effects of stress during gestation

The social stress applied during gestation was indeed stressful for the treated sows as they were all involved in aggressive interactions with the pairs of larger sows and received physical injuries in the form of superficial skin lesions. The physical and psychological stress associated with aggression in sows is known to increase cortisol and catecholamine levels as well as heart rates, which are indicative of activation of the HPA axis and the sympathetic nervous system (Marchant et al., 1995; Jarvis et al., 2006; Couret et al., 2009b; Otten et al., 2002). Although aggression between unfamiliar sows usually decreases within the first 48 h (Arey and Edwards, 1998), fresh lesions were still seen a week after mixing in the present study, which suggests that aggressive behaviour continued to occur throughout the week. Thus, the sows likely remained stressed during each week of social stress. The importance of exposing sows to at least two subsequent social groupings with different pairs of sows was demonstrated by the treated sows that won as many fights as resident sows during the first mix, but less during the second mix. In addition, the overall number of fights was lower after the second mix. Likewise, Couret et al (2009b) reported a progressive decline of agonistic interactions and skin lesions after the third regrouping on sows submitted to a repeated social mixing stress (8 times) between d 77 and 105 of gestation. A similar profile of decreasing effects on aggressive behaviour was shown in growing pigs submitted to repeated groupings (Coutellier et al., 2007). The decreased offensive acts and lesions could reflect the adoption of a new coping strategy to a changing and aversive environment (Bolhuis et al., 2004).

5.5.2 Impact on postures and activities

During early lactation, it is important for piglet survival that the sows remain primarily in a lateral lying posture to provide piglets with warmth and access to the udder (Pedersen et al., 2003). Given that treated sows spent more time lying ventrally than control sows in early lactation, thus restricting access to the udder, this may be indicative of a lower motivation to nurse (Farmer and Robert, 2003). Similar results were found by Csermely and Nicosia (1991) when comparing the maternal behaviour of sows that were either dominant or subordinate during group housing in gestation. They found that the lower ranking sows spent more time lying ventrally than higher ranking sows, displayed more restlessness and terminated more nursing bouts in early lactation thereby displaying poorer maternal behaviour overall. This may have been due to the stress the lower ranking sows experienced during gestation as in our study.

The physical nature of the housing conditions may have influenced lying time, since the enriched sows had more surface area on which to lie laterally in late lactation. Our results are in accordance with other studies in which sows in farrowing crates spent more time lying and less time exploring their environment than loose housed sows (Cronin and Smith, 1992; Cronin et al., 1994; Arey and Sancha, 1996; Johnson et al., 2001). As lactation progresses, the increased time spent lying ventrally by sows in crates may be a strategy used to prevent udder stimulation and attention from their piglets since they can't otherwise get away from the litter (De Passillé and Robert, 1989; Valros et al., 2002). Furthermore, we found that enriched sows tended to spend less time sitting than standard housed sows in late lactation, which is in accordance with other studies as well (Cronin et al., 1992; Hötzel et al., 2004; Jarvis et al., 2004). Even though in our study this posture may not always have been detected correctly by the accelerometers (Ringgenberg et al., 2010), it is in any case a difficult result to interpret in terms of relevance to maternal behaviour. Many piglet crushings were found to occur when the sows moved from a sitting to a lying posture, thus, sows that spent more time sitting also crushed more piglets (McGlone and Morrow-Tesh, 1990; Cui et al., 2011). Sitting during lactation may also be an alternative to lying ventrally to prevent the piglets from accessing the udder (Hötzel et al., 2004).

When sows are standing they are in an aroused state, which in terms of animal welfare, may be interpreted as positive or negative. Sows housed in an enriched environment often spend more time standing than confined sows simply due to the larger space allowance, and the ability to perform foraging and exploratory behaviour (Arey and Sancha, 1996). In terms of maternal behaviour however, standing in late lactation may be a way for crated sows to prevent suckling, while in enriched conditions, it may simply be due to foraging and exploring. In our study, there was an interaction between treatments for the time spent standing in late lactation. In enriched housing, the time spent standing was greater for stressed sows while in the standard housing, stressed sows stood less compared to control sows. This result, although hard to explain, suggests that a social stress during gestation modulates the time spent active by sows depending on the type of housing.

The stress in gestation also resulted in a decreased time spent in the nesting area by enriched sows in late lactation. With our pen design, even though the sow had to step over a barrier to change areas, the piglets were unable to follow the sow into the dunging area only for the first few days after birth. Thus, the increased time spent in the dunging area by the treated sows does not necessarily reflect them getting away from their piglets, but may rather reflect a decreased preference for the straw compared to sows that did not experience stress during gestation.

5.5.3 Impact on social contacts

It has been hypothesized that the purpose of social contacts between the sow and the piglets in early lactation is to create a bond between them. This bond may increase piglet welfare as fewer piglet crushings have been observed in sows that nosed their piglets more (Petersen et al., 1990; Andersen et al., 2005; Wischner et al., 2010).

In the present experiment, there was only a slight effect of stress during gestation on the number of contacts with the piglets, with treated sows tending to show more contacts during the post-nursing period in late lactation. However, significantly fewer social contacts with the piglets were initiated by sows housed in standard crates than enriched sows on day 6 of lactation. More specifically, enriched sows exhibited more contacts with their piglets than standard housed sows during the pre-nursing period in early lactation and during the resting period in late lactation. These results are in agreement with other studies which found that sows and gilts housed in farrowing crates initiated fewer nose-to-nose contacts with their piglets than sows housed in farrowing pens (Cronin and Smith, 1992; Cronin et al., 1996), and that there was a greater association with increased surface area rather than environmental enrichment (Jarvis et al., 2004). The restrictive nature of the crate may thus negatively affect maternal bonding with the piglets.

5.5.4 Impact on maternal responsiveness

Standing by the sow in response to a simulated crushed piglet vocalization is the only behaviour that would in theory save the piglet from being crushed (Hutson et al., 1992). In our study, the simulated piglet crush test only showed a tendency for treated sows to take longer to stand than control sows as a result of the piglet screams, thus the social stress during gestation had a slight negative influence on maternal responsiveness. However, the responses to this test were low with close to half of sows not responding. Moreover, no relation was found between the response to the test and the numbers of piglets crushed in other studies (Spinka et al., 2000; Grandinson et al., 2003; Held et al., 2006). Only Andersen et al. (2005) reported that sows that had not crushed any piglets showed a shorter latency to respond behaviourally to the test than the sows that did. Given the general low reactivity of lactating sows to this test and the lack of relation with accidental piglet crushings, this test is unlikely to accurately reflect maternal ability in sows.

Under commercial conditions, piglets are weaned from the sow after only a few weeks of lactation. Separation of the piglets from the sow results in strong behavioural responses, high levels of locomotion, escape attempts, and vocalizations from both the sow and the piglets (Fraser, 1975; Weary et al., 1996a; Pajor et al., 1999; Illmann et al., 2002). In an experimental setting, sows have been shown to respond significantly more to an isolated piglet grunts playback than to white noise (Weary and Fraser, 1995; Weary et al., 1996a). Weary et al. (1996a) assessed the behavioural responses of sows during mid lactation to isolated piglet vocalization playbacks that were either from thriving or needy piglets. Sows responded more to calls of needy piglets by vocalizing more, being more active and staying longer in the speaker area. In our study, the social stress resulted in a decreased maternal response in terms of the latency to vocalize, as treated sows took longer to respond to the playbacks by grunting than control sows. Sows started to vocalize on average 14.49 ± 2.38 s after the start of playbacks, which is similar to Weary et al. (1996a) where the latency to vocalize was approximately 20 s. Furthermore, the durations of vocalizations for both studies were shorter during the playback than after with durations of 0.56 ± 0.022 s and 0.83 ± 0.021 s in Weary et al. (1996a) and 0.43 ± 0.024 s and 1.06 ± 0.045 s in our study. Given the similarity of these results, the vocal responses of sows to playbacks of isolated piglet grunts are likely independent of the design of the test pen which was smaller in our study than in Weary et al. (1996a) and appear to be a good indicator of sow responsiveness. On the other hand, the interactions observed between treatments for the latency to first movement and the time spent in the speaker zone (for both phases) did not support any compensatory effect of the enriched farrowing pen on the social stress. These results are thus difficult to interpret and may be due to the size of the test pen and the fact that the initial location of the sow, which was not controlled for, could have influenced the time it took for the sows to enter the speaker zone.

5.5.5 Impact on production

The lack of impact of the social stress during gestation on sow and piglet production parameters is consistent with other studies in pigs that used either a social mixing, ACTH injections or rough handling as stressors during mid-gestation (Jarvis et al., 2006; Kanitz et al., 2006; Otten et al., 2007; Lay et al., 2008), although a tendency for piglets from stressed sows to weigh less at birth than control piglets was reported by Haussmann et al. (2000) and Kranendonk et al. (2006b). On the other hand, housing conditions affected sow production data with enriched sows consuming less feed during lactation and weighing less on d 3 and 21 of lactation than standard housed sows, although there was no difference in back-fat thickness between treatments. The location of the feeder in the enriched pen may also have limited feed intake as the sows had to leave the nesting area to get to it, whereas for crated sows, their feeder was always in front of them. However, this is unlikely as Cronin et al. (2000) found that sows housed in enriched farrowing pens consumed more feed than crated sows during the third week of lactation with a pen design and feeder placement similar to ours. During the trial, although no measurements were taken, it was noticed that some sows consumed a fair quantity of straw, which could have decreased their appetite.

Studies comparing standard farrowing crates to loose housing systems generally found that there were more piglet deaths due to accidental crushing by the sow in the loose housing systems, although this was often offset by fewer piglets dying of other causes in pens compared to crates (Blackshaw et al., 1994; Weary et al., 1996b; Cronin et al., 2000; Weber et al., 2007). Johnson et al. (2001) and Pedersen et al. (2010) on the other hand, did not find differences in mortalities due to overlay by the sow. In our study, housing conditions only tended to impact piglet mortality with more piglet deaths by crushing in enriched pens than crates. The lack of impact on other performance data (such as average daily gain) may be due to the fact that piglets were not provided with any creep feed and did not have access to the feed of the sow. Indeed, Oostindjer et al. (2010) found that piglets reared in a straw enriched farrowing pen with access to creep feed beside the sow feeder had greater growth pre-weaning than piglets reared in standard farrowing crates with separate feeders.

5.6 Conclusion

This study was the first to demonstrate that a social stress during gestation may negatively impact maternal behaviour in sows post-partum. Even though the enriched farrowing environment positively influenced maternal behaviour, it was not directly counteractive to the effects of the social stress in mid-gestation. Data from this project involving piglet behaviour as a result of prenatal stress and housing in lactation are currently being analyzed. Further work is required to investigate the role that piglets play in mediating the maternal behaviour of the dam with regard to a stress treatment during gestation.

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Table 5.1: Mean (± SEM) number of fights, bullying episodes and aggressive acts initiated and won by the treated sow (T) or the resident sows (R) during a 6-h period following mixing at d 39 and 59 of gestation.

		Mixing at d 39	Mixing at d 59
Number of fights	Initiated by T	4.32 ± 0.99	0.27 ± 0.20
	Initiated by R	8.74 ± 3.27	2.09 ± 0.37
	Won by T	1.05 ± 0.31	0.27 ± 0.20
	Won by R	1.05 ± 0.21	1.55 ± 0.31
	No winner	11.11 ± 4.71	0.55 ± 0.31
Number of bullying episodes	Initiated by T	0.75 ± 0.36	0.65 ± 0.65
	Initiated by R	2.56 ± 0.60	2.47 ± 0.49
Number of aggressive acts	Initiated by T	10.40 ± 2.65	5.25 ± 4.16
	Initiated by R	27.90 ± 5.33	32.15 ± 5.65

Table 5.2 : Mean number of fresh scratches and lesions (> 2 cm) before and during each week of mixing.

	Mix 1 (d 39-45)	Mix 2 (d 59-65)
Before grouping	1.55 ± 0.34	1.2 ± 0.31
24 h after grouping	46.55 ± 7.78	41.35 ± 4.96
7 d after grouping	32.25 ± 8.72	21.5 ± 4.21

Table 5.3: Impact of mixing treatment during gestation and housing treatment during lactation on the latency of sows to respond (mean ± SEM) to the simulated piglet crush test and to respond vocally to the isolated piglet playback test.

		Enriched housing (E)		Standard housing (S)		*P*-value		
		Control (C)	Treated (T)	Control (C)	Treated (T)	M	H	M x H
Simulated piglet crush test		13.5 ± 5.07 s	23.2 ± 6.41 s	20.8 ± 7.17 s	29.0 ± 5.85 s	0.20	0.37	0.19
	n[y]	8	5	4	6			
Isolated piglet playback test	Phase 1	12.74 ± 2.35 s	15.68 ± 2.35 s	11.03 ± 2.47 s	18.54 ± 2.35 s	**0.035**	0.81	0.34
	Phase 2	2.67 ± 0.84 s	2.19 ± 0.73 s	3.25 ± 1.03 s	1.67 ± 0.56 s	0.30	0.38	0.41

[y] *n* = number of sows that responded (response 1 or 2) to the piglet scream, sows with a response of 0 (no reaction to stimulus) were excluded.

[z] M = mixing treatment in gestation (T or C), H = housing treatment (E or S), M × H = interaction

Table 5.4: Impact of mixing treatment during gestation and housing treatment during lactation on the mean percent of time (± SEM) spent in each posture by sows on d 5 and 19 of lactation.

		Enriched housing (E)		Standard housing (S)		[y] *P*-value		
Posture	Day	Control (C)	Treated (T)	Control (C)	Treated (T)	M	H	M × H
Lying ventrally, %	5	7.42 ± 1.47	11.24 ± 1.20	6.84 ± 1.22	10.93 ± 1.62	**0.0072**	0.75	0.92
	19	14.77 ± 1.45	14.43 ± 1.30	25.17 ± 5.39	16.68 ± 3.10	0.20	**0.067**	0.23
Lying laterally, %	5	80.93 ± 2.31	76.50 ± 3.21	83.48 ± 1.72	80.39 ± 2.16	0.14	0.20	0.79
	19	71.32 ± 2.23	70.67 ± 1.58	56.41 ± 6.69	68.63 ± 4.19	0.19	**0.056**	0.14
Standing, %	5	8.81 ± 0.87	8.57 ± 1.13	8.15 ± 0.88	6.85 ± 1.05	0.45	0.25	0.60
	19	11.09 ± 0.97	13.86 ± 1.00	12.80 ± 0.73	9.13 ± 0.84	0.62	0.10	**0.001**
Sitting, %	5	2.84 ± 1.26	3.86 ± 2.79	1.52 ± 0.50	1.83 ± 0.38	0.72	0.31	0.86
	19	2.82 ± 1.33	1.04 ± 0.32	5.63 ± 2.94	5.55 ± 2.19	0.64	**0.074**	0.67

[y] M = mixing treatment in gestation (T or C), H = housing treatment in lactation (E or S), M × H = interaction

Table 5.5: Impact of mixing treatment during gestation on sow behaviour on d 5 and 19 of lactation in enriched housing (mean ± SEM)

	Day	Control (C)	Treated (T)	*P*-value
Movement between nesting	5	11.36 ± 1.75	10.30 ± 1.83	0.68
and dunging areas, freq [x]	19	13.09 ± 1.35	16.30 ± 1.42	0.12
Total time in nesting area, %	5	65.43 ± 9.95	54.96 ± 10.43	0.48
	19	51.31 ± 7.79	22.18 ± 8.18	**0.018**
Lying ventrally [y], %	5	4.45 ± 0.96	5.77 ± 1.55	0.47
	19	8.51 ± 1.67	3.61 ± 1.07	**0.028**
Lying laterally [y], %	5	56.52 ± 8.81	44.19 ± 8.28	0.32
	19	41.25 ± 7.56	17.98 ± 6.33	**0.032**
Standing [y], %	5	2.12 ± 0.27	1.67 ± 0.34	0.32
	19	2.5 ± 0.35	3.57 ± 0.53	0.11
Sitting [y], %	5	2.35 ± 1.09	3.32 ± 2.68	0.73
	19	0.94 ± 0.38	0.32 ± 0.12	0.16

[x] Observation period of 24 h

[y] Time spent in each posture in the nesting area only.

Table 5.6: Impact of mixing treatment during gestation and housing treatment during lactation on the number of sow-initiated contacts (means ± CI) during a 6-h recording on d 6 and 20 of lactation, and according to the step of the suckling sequence or the activity.

			Enriched housing (E)		Standard housing (S)		*P*-value[x]		
		Day	Control (C)	Treated (T)	Control (C)	Treated (T)	M	H	M x H
Contact around nursing periods	Pre-nursing	6	6.09 ± 1.11	6.60 ± 1.17	3.80 ± 1.17	2.10 ± 1.17	0.61	**0.0056**	0.34
		20	3.55 ± 1.25	6.20 ± 1.31	3.90 ± 1.31	4.50 ± 1.31	0.22	0.61	0.43
	Nursing	6	2.55 ± 0.60	2.50 ± 0.63	2.50 ± 0.63	0.50 ± 0.63	0.11	0.11	0.13
		20	0.55 ± 0.30	0.90 ± 0.32	0.50 ± 0.32	0.20 ± 0.32	0.93	0.25	0.31
	Post-nursing	6	5.18 ± 1.73	9.30 ± 1.81	5.10 ± 1.81	4.60 ± 1.81	0.32	0.19	0.21
		20	4.82 ± 1.41	7.00± 1.48	3.40 ± 1.48	6.40 ± 1.48	**0.085**	0.49	0.78
	Between nursing	6	13.36 ± 2.95	11.30 ± 3.09	10.80 ± 3.09	10.50 ± 3.09	0.70	0.59	0.77
		20	18.00 ± 3.74	20.30 ± 3.92	16.30 ± 3.92	18.10 ± 3.92	0.60	0.62	0.95
Other contact	Active	6	15.55 ± 3.34	15.00 ± 3.50	13.30 ± 3.50	11.80 ± 3.50	0.77	0.44	0.89
		20	21.64 ± 4.41	25.00 ± 4.63	20.60 ± 4.63	25.90 ± 4.63	0.35	0.99	0.83
	Resting	6	9.09 ± 3.24	12.20 ± 3.40	6.40 ± 3.40	5.40 ± 3.40	0.76	0.17	0.54
		20	4.73 ± 1.74	8.50 ± 1.83	3.00 ± 1.83	3.10 ± 1.83	0.29	**0.056**	0.32
	Total	6	27.18 ± 4.19	29.70 ± 4.39	22.20 ± 4.39	17.70 ± 4.39	0.82	**0.058**	0.42
		20	26.91 ± 4.78	34.40 ± 5.01	24.10± 5.01	29.20± 5.01	0.21	0.42	0.81

[x]M = mixing treatment in gestation (T or C), H = housing (E or S), M × H = interaction

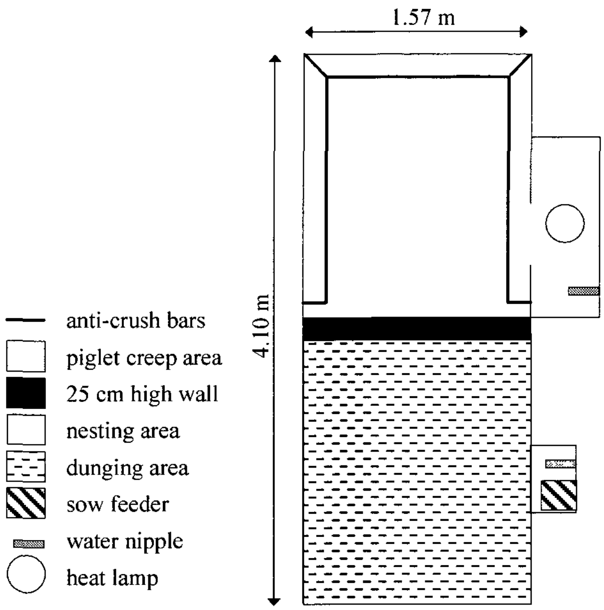

Figure 5.1: Enriched pen with straw in the nesting and piglet creep areas.

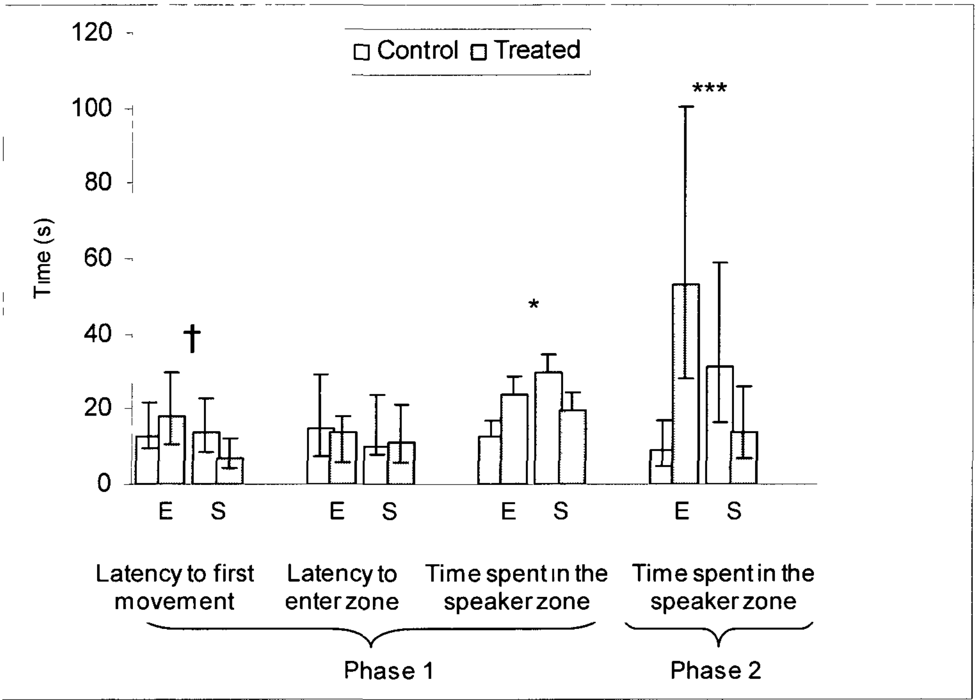

Figure 5.2: Impact of mixing treatment during gestation and housing treatment during lactation on sow responses to the isolated piglet playback test during phase 1 (playback) and 2 (silence). Data presented as means ± SEM for time spent in speaker zone in phase 1, and means ± CI for all other data.

[1]E = enriched lactation housing; S=standard lactation housing

The "zone" refers to the square in front of the speaker.

† $P < 0.1$, * $P < 0.05$, *** $P < 0.001$ for the interaction effect between gestation and lactation treatments.

Chapter 6: General summary and conclusions

This thesis was an investigation of the influence of two factors on components of maternal behaviour in sows, namely, a social mixing stress during gestation and an enriched environment during lactation. Previous research has investigated the impact of stress during gestation on the physiology and behaviour of piglets (Jarvis et al., 2006; Kranendonk et al., 2006b). However, the impact of stress during gestation on the maternal behaviour of sows during an entire lactation had not been studied before. It is known that in humans and rodents, stressful situations during gestation result in depressed maternal care (Slattery and Neumann, 2008; O'Hara, 2009). Furthermore, as enriched environments during lactation improve the maternal behaviour of sows compared to the conventional farrowing crates (Pajor et al., 1999; Cronin et al., 2000), we decided to test the hypothesis of a counteractive effect of enrichment in lactation on the maternal behaviour of sows stressed during gestation. Given that observations on maternal behaviour are often labour-intensive and time-consuming, we also developed and validated an automatic method to detect postures in sows. This was then subsequently used to study the maternal behaviour of sows in terms of postural budgets.

6.1 Overview of results

In the first study, we aimed to develop and validate a methodology to automatically detect postures in sows using accelerometers. Given that the accelerometers could be programmed in a fast recording mode, the detection of stepping behaviour was also investigated. To detect postures, two accelerometers were used: one on a hind leg of the sow and the other on the back. The simultaneous use of these two data loggers programmed to record acceleration signals every five seconds and to convert these to degrees of tilt allowed for the detection of the following postures: standing, lying ventrally, lying laterally and sitting. The first three postures were detected with a high sensitivity and specificity. However, the detection of the sitting posture was not as successful. Individual calibration should thus be used if sitting is a posture that needs to be detected accurately. The standing posture alone could also be successfully detected using just the hind leg accelerometer. In terms of stepping behaviour, one accelerometer was fastened to a hind leg of a sow and recorded acceleration signals every tenth of a second while the sow was standing during feeding. The accelerometers were validated for the use of counting individual steps during thirty minutes.

The main objective of this thesis, namely the investigation of maternal behaviour of sows according to a social stress in gestation and enrichment during lactation, were met in the second study. We found that mixing sows with two unknown and larger sows twice over two separate weeks during mid gestation negatively affected maternal behaviour. Stressed sows spent more time lying ventrally in early lactation, which is synonymous with the piglets having less access to the udder, and they took longer than control sows to respond vocally to the isolated piglet playback test. Interestingly, when only looking at sows housed in enriched pens during lactation, the ones that were stressed during gestation spent less time than control sows in the nesting area; thus the stress resulted in a decreased use of environmental enrichment. In terms of the impact of housing during lactation on maternal behaviour, we found that enriched sows tended to spend less time lying ventrally and more time lying laterally in late lactation and they tended to display more social contact in early lactation than standard housed sows.

Therefore, even though the environmental enrichment during lactation had positive effects on maternal behaviour, it did not directly counteract the effects of social stress.

6.2 Implications for the swine industry and future research

As group housing of gestating sows is becoming more common due to new regulations and pressure from consumers, the need for effective pen designs and management strategies is becoming increasingly important. Even though group housing has many benefits for the welfare of sows, this thesis demonstrated that a stressful social environment during gestation can have a negative impact on some components of maternal behaviour. Although productivity was not affected in this study, in commercial conditions, gestational social stressors may be longer in duration which may lead to greater impact in lactation. It would therefore be interesting to compare the impact of different commercial group housing systems of gestating sows on their subsequent maternal behaviour and productivity.

In terms of the farrowing environment, this research confirmed that an enriched farrowing pen is beneficial for the performance of maternal behaviour compared to barren farrowing crates. Even though crates are still the standard in the swine industry, advantages may be gained by using enriched pens as it has been shown that sows that were group-housed during gestation show a high level of restlessness at farrowing if housed in crates (Boyle et al., 2002). Again, it would be interesting to compare different types of environmental enrichment, either indoors or outdoors, in terms of their impact on maternal behaviour and potential counteractive effect on social stress in gestation.

Further work is underway from the same study to determine the impact of a prenatal stress on piglet behaviour in the home-pen and during stressful situations. In addition, the potential compensatory effects of an enriched environment during lactation on the prenatal stress will be investigated.

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