UNIVERSITY OF COPENHAGEN
FACULTY OF HEALTH AND MEDICAL SCIENCES

Loose housing or temporary confinement of sows in designed farrowing pens

PHD THESIS 2015 · JANNI HALES PEDERSEN

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PhD Thesis

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HERD – Centre for Herd-oriented Education, Research and Development

Department of Large Animal Sciences

Faculty of Health and Medical Sciences

University of Copenhagen

2015

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ISBN 978-87-7611-871-6
Printed by SL grafik, Frederiksberg C, Denmark (www.slgrafik.dk)

PREFACE AND ACKNOWLEDGEMENTS

This thesis is intended to fulfil the requirements for the PhD degree at the Faculty of Health and Medical Sciences, University of Copenhagen. This PhD project was funded by the Pig Levy Foundation and was conducted from February 2012 to February 2015 at the Department of Large Animal Sciences. Funding for the experimental work was also provided by The Danish Rural Development Programme 2007-2013/The European Agricultural Fund for Rural Development.

This thesis would not have been completed, had it not been for the people who helped me on this three-year journey. First of all I would like to thank my supervisors, Christian and Vivi, for inspiring me and for always pushing me. For some reason you have great faith in me and I am deeply grateful for your guidance, support and constructive criticism. You have made me grow as a scientist but also as a person, and I would definitely not be where I am today if it wasn't for your invaluable commitment and amazing determination.

I would also like to acknowledge the staff and owners of all the herds that have participated in the experiments conducted in this PhD project. I know it is not easy when experiments are interfering with the daily work and your participation is highly valued. I owe the people at Krannestrup my deepest gratitude for believing in the SWAP pen and for opening their doors for new ideas. I can truthfully say that this project had not been the same without you. In relation to development of the SWAP pen I would also like to express my appreciation of everyone at Jyden and everything they did to bring the option of confinement to life.

The experiments in this thesis have been conducted in cooperation with the Danish Pig Research Centre. This could not have been done without the aid from the technicians; Mogens Jakobsen, Erik Bach, Hanne Nissen, Ann Edal and Jens Martin Strager. In addition, Jens Ove Hansen has been a tremendous help. I owe me deepest gratitude to Mai Britt Friis Nielsen for never ending patience and priceless statistical support. I also wish to thank Kenneth Damholt Kristensen for technical assistance and for teaching me things I never thought I would understand.

The experimental work furthermore involved a lot of people, to whom I am very thankful: Alexander Grahofer, Louise Oxholm, Pernille Weber, Camilla Højgaard, Charlotte Amdi, Michele Devreese, Julie Krogsdahl and Pia Brandt. Your efforts are much appreciated.

I would also like to take this opportunity to thank the people at Rivalea in Australia for welcoming me with open arms. Especially Rebecca Morrison, for taking me under your wings, and Ash and Sam, for being amazing roomies. I definitely learned a lot from all of you and was fortunate to establish some pretty unique friendships to. Ash – sincerely thank you for being there for me in the final stages of this project.

To colleagues at the Department of Large Animal Sciences and fellow PhD students: it has been a pleasure to work with all of you. Special thanks to Anja and Charlotte for fruitful discussions about pigs and so many other things. And thanks to Rikke Buhl for helping me and for making sure that I did not only spend time with pigs but also with horses.

Finally, I would like to thank my family and friends for never ending help and support. I am surrounded by the best of people, who are always there when I need it, and for this I can never thank you enough.

SUMMARY

The overall objective of this project was to study piglet mortality in designed farrowing pens and to investigate the effects of temporary confinement of sows on piglet mortality as well as on sow behaviour and physiology. The aims of this thesis was therefore to: 1) study piglet mortality in designed farrowing pens and traditional farrowing crates, 2) study if farrowing progress and early piglet mortality was affected by confinement from two days before expected farrowing to four days after farrowing, and 3) study if piglet mortality, sow behaviour and saliva cortisol concentration was affected by use of temporary confinement for four days after farrowing in designed farrowing pens.

The aims were addressed in three experimental studies. The first study was conducted in three commercial piggeries that had both designed farrowing pens and farrowing crates in their farrowing units. The second study was conducted in a herd where farrowing pens were equipped with a swing-side crate and the third study was conducted in a herd with designed farrowing pens equipped with an option of confinement.

Piglet mortality in designed farrowing pens was greater than in farrowing crates in three different herds. A proportion of sows had acceptable level of piglet mortality in pens, but pens did not seem to be a robust type of housing. Confinement of sows from day 114 of gestation had no influence on farrowing progress compared to sows that were loose housed but the results did suggest that confinement for four days after farrowing reduced piglet mortality compared to loose housed sows. Results on temporary confinement of sows in designed farrowing pens showed that confinement for four days after farrowing could reduce piglet mortality in that period compared to loose housed sows. However, confinement from before farrowing was necessary to reduce total piglet mortality. The results also emphasized that the period from the birth of the first piglet to litter equalisation was important as a significant proportion of live born deaths occurred in this period. Results on the effects of temporary confinement in designed farrowing pens moreover suggested that confinement for four days after farrowing influenced sow behaviour, although only to a minor degree as very little activity occurred. Behavioural differences were not reflected in saliva cortisol concentrations but cortisol response decreased if sows were confined before farrowing.

The idea of temporary confinement of sows as a means to achieve low piglet mortality and at the same time impose as little detriment to the sow as possible was supported by the findings in this thesis. Further improvement of strategies for temporary confinement could potentially ensure high level of sow and piglet welfare in designed farrowing pens.

SAMMENDRAG

Hovedformålet med dette projekt var at studere pattegrisedødelighed i designede farestier til løse søer og at undersøge effekterne af midlertidig begrænsning af soen på pattegrisedødelighed samt søernes adfærd og fysiologi. De specifikke formål var at: 1) undersøge pattegrisedødelighed i designede farestier til løse søer samt traditionelle kassestier, 2) undersøge om faringsforløb og tidlig pattegrisedødelighed var påvirket af brug af boks fra to dage før forventet faring til fire dage efter faring, 3) undersøge om pattegrisedødelighed, søernes adfærd og koncentrationen af cortisol i spyt var påvirket af midlertidig begrænsning i fire dage efter faring i designede farestier til løse søer.

De opstillede mål blev nået ved gennemførelse af tre eksperimentelle forsøg. Første forsøg blev gennemført i tre kommercielle so-besætninger, der havde både designede farestier til løse søer og kassestier i deres farestald. Andet forsøg foregik i en besætning, hvor farestierne var udstyret med en fareboks, der kunne åbnes, og et tredje forsøg blev gennemført i en besætning med designede farestier, hvor der var mulighed for at begrænse søernes bevægelse.

Pattegrisedødeligheden i designede farestier til løse søer var højere end i kassestier. En andel af søerne havde acceptable præstationer i løsdriftsstierne, men løsdriftsstierne kunne ikke betegnes som et robust system. Brug af boks fra dag 114 af drægtigheden havde ingen indflydelse på faringsforløbet i forhold til søer, der var løse. Resultaterne pegede imidlertid på, at brug af boks i fire dage efter faring reducerede pattegrisedødeligheden i forhold til løse søer. Resultaterne af midlertidig begrænsning af søerne i designede farestier viste, at begrænsning i fire dage efter faring kunne reducere pattegrisedødeligheden i den periode i forhold til løse søer. Det var imidlertid nødvendigt at begrænse søerne før faring for at opnå en reduktion i totalpattegrisedødelighed. Resultaterne understregede desuden vigtigheden af perioden fra fødsel af første gris til kuldudjævning, da en betydelig del af dødeligheden skete i denne periode. Resultaterne af midlertidig begrænsning i designede farestier til løse søer viste endvidere, at begrænsning i fire dage påvirkede søernes adfærd men kun i mindre grad, da der var et generelt lavt niveau af aktivitet. De adfærdsmæssige forskelle blev ikke genfundet i koncentrationen af cortisol i spyt, men der var lavere cortisolrespons, hvis søerne var begrænset før faring.

Ideen om midlertidig begrænsning af søerne som middel til at opnå lav pattegrisedødelighed men samtidig med mindst mulig indvirkning på søerne blev understøttet af resultaterne i dette projekt, og yderligere forbedringer af strategier for midlertidig begrænsning kan potentielt sikre god velfærd for både søer og pattegrise i designede farestier til løse søer.

List of Papers

Paper I:

Hales J., V.A. Moustsen, M.B.F. Nielsen and C.F. Hansen. 2013. **Higher preweaning mortality in free farrowing pens compared with farrowing crates in three commercial pig farms**. Animal 8 (01), 113-120.

Paper II:

Hales J., V.A. Moustsen, A.M. Devreese, M.B.F. Nielsen and C.F. Hansen. 2015. **Comparable farrowing progress in confined and loose housed hyper-prolific sows.** Livestock Science 171, 64-72.

Paper III:

Hales J., V.A. Moustsen, M.B.F. Nielsen and C.F. Hansen. **Temporary confinement of loose housed hyper-prolific sows reduces piglet mortality.** Submitted for publication.

Paper IV:

Hales J., V.A. Moustsen, M.B.F. Nielsen and C.F. Hansen. **Confinement of sows in SWAP farrowing pens to day four of lactation influences sow behaviour and saliva cortisol concentration.** Unpublished manuscript.

CONTENTS

INTRODUCTION

Animal welfare is becoming increasingly important to the public and intensive farming systems where animals are housed in barren environments or confined spaces are often perceived as having a poor welfare standard for the animals. Attention to welfare issues in relation to sow housing has led to a European ban on gestation stalls that came into force in 2013 (Council of Europe, 2001). So far the use of farrowing crates is only restricted in Switzerland, Sweden and Norway, although work conducted in the EU has identified that farrowing crates "severely restrict sow behaviour and freedom of movement" (European Food Safety Authority, 2007). However, at the same time the European Food Safety Authority also recommended that non-confined lactation housing is only implemented if piglet mortality does not exceed the level of crated systems and that piglet mortality should be reduced (European Food Safety Authority, 2007). Experimental comparisons of piglet mortality in pens and crates show wide variations and a risk of increased mortality if sows are loose housed (Arey, 1997; Marchant et al., 2000; Andersen et al., 2007) and only a few large scale studies of piglet mortality in loose housed systems in commercial settings have been conducted (Andersen et al., 2007; Weber et al., 2009; KilBride et al., 2012). The risk of increased piglet mortality is one of the major barriers for implementation of loose housed farrowing systems. The design of a commercially viable loose housed system for farrowing and lactating sows should consider the needs of the sow, the piglets and the producer at the same time (Baxter et al., 2011a). Further development of designed farrowing pens is needed along with investigations of the performance levels and impacts of these systems to achieve a commercially viable solution for alternative farrowing housing.

Piglet mortality

Studies have shown that sows in crates experience increased stress around farrowing compared to sows in pens (Jarvis et al., 1997; Jarvis et al., 2001) and confinement might affect opioid regulation of oxytocin (Lawrence et al., 1997). Increased stress around farrowing has in some studies been associated with a longer farrowing process (Thodberg et al., 2002a; Oliviero et al., 2008), which is related to increased rate of stillbirth (van Dijk et al., 2005; Vanderhaeghe et al., 2013). However, studies comparing herds with loose housed sows and herds with crated sows have shown an average stillbirth rate within the range of 0-1 piglets per litter and no differences between different systems (Weber et al., 2007; KilBride et al., 2012). Reports regarding comparisons of pens and crates in the same herd have also described similar rates of stillbirth with an average of approximately 0.7 stillborn piglets per litter (Cronin et al., 2000; Pedersen et al., 2011a). However, none of these studies aimed at comparing stillbirth rates and the material was probably insufficient to support any substantial conclusions regarding changes in stillbirth rates.

The majority of live born piglet deaths occur within the first days of life regardless of the sow housing system. Studies comparing sows in pens with sows in crates in experimental settings using small sample sizes (n: 8-15) found a higher live born mortality in pens (approximately 30 %) compared to crates (approximately 14%) (Blackshaw et al., 1994; Bradshaw and Broom, 1999; Marchant et al., 2000). Marchant et al. (2001) (n = 24) reported a live born mortality rate of 25% over the first seven days of lactation in a study of sow behaviour in pens. A comparison of the performance of sows in crates and Werribee Farrowing Pens in a commercial setting (pens: n = 66, crates: n = 80) showed no difference in live born mortality (crates: 15.5%, pens: 17.5%) (Cronin et al., 2000). Weber et al. (2007) and KilBride et al. (2012) compared piglet mortality in herds with pens and herds with crates and found similar rates of live born mortality in both systems. The average live born mortality rate of 13-14% in Weber et al. (2007) corresponded to the rate of 15.2% found in a Norwegian study of mortality in herds with pens (Andersen et al., 2007). However, in the study by Andersen et al. (2007), the range of mortality was 5-25%, indicating that even though the average level was relatively low, there was a great variability in mortality rates between herds.

The main cause of live born piglet deaths is crushing (Svendsen et al., 1986; Marchant et al., 2000). Weber et al. (2007) reported more piglets crushed in pens compared with crates (pens: 0.62 piglets/litter, crates: 0.52 piglets/litter) and likewise Jarvis et al. (2005) found a greater crushing risk if gilts were housed in pens where 1.4 piglets died from crushing compared to 0.6 piglets in crates. Similarly, Cronin et al. (2000) found a trend for an increased crushing rate in loose housed sows compared to crated sows with 45% and 20% of piglets dying from crushing in pens and crates, respectively. KilBride et al. (2012) also found a trend towards an increased risk of crushing in loose systems compared to crates. According to Jarvis et al. (2005), the risk of crushing is higher in certain litters than in others due to individual differences between sows. However, this individual difference is expressed more in pens than in crates indicating that restricting sows in crates decreases the variation between sows (Jarvis et al., 2005). Sow posture changes such as lying down from standing or rolling have been associated with crushing and are thus in focus when it comes to reducing crushing (Weary et al., 1998; Marchant et al., 2001; Danholt et al., 2011).

Studies of piglet mortality display large variability, and while it is uncertain whether housing affects the number of stillborn piglets, there is a general agreement that there is an increased risk of crushing in pens. However, further within-herd studies of piglet mortality in designed farrowing pens and crates are needed to investigate if performance in pens, all other things being equal, is similar to that in crates.

Effects of confinement on sow behaviour and physiology

Behavioural effects

The purpose of the farrowing crate is to physically restrict the sow from moving around and thereby prevent crushing of the piglets. Under commercial conditions sows are placed in the farrowing crates a number of days before farrowing, where piglet protection is not yet necessary. Before onset of farrowing sows perform nest building behaviour that involves an increased level of activity regardless of housing system (Lawrence et al., 1994). As a consequence of the physical restriction in crates sows in pens and crates display different patterns of nest building behaviour in the pre-partum period (Jarvis et al., 1997; Jarvis et al., 2002; Damm et al., 2003). The activity seen during nest building is replaced by a more inactive behavioural pattern around farrowing. In a Danish study of five pen types, the frequency of lying down decreased from approximately 40 times per day on the day before farrowing to approximately 8 times per day on the day of farrowing (Moustsen et al., 2007). In Biensen et al. (1996), the frequency of postural changes was not different between pens and crates, but declined from the two hour period before (pens: 9.5, crates: 12.4) to the two hour period after farrowing (pens: 1.8, crates: 1.4). At the onset of farrowing sows in pens and crates were found lying laterally in 50-70% of observations (Jarvis et al., 1997; Jarvis et al., 2001). During the first eight hours after farrowing, both penned and crated sows spent the majority of time (58-60 min/h) lying down and only a few minutes per hour standing (Jarvis et al., 2004). However, the first two hours after onset of farrowing differed as the occurrence of postural changes was higher compared to the rest of the peri-parturient period and penned sows spent more time standing/walking (Pedersen et al., 2003; Jarvis et al., 2004). Postural changes during the first hours of farrowing may be a part of natural farrowing behaviour as sows in pens have shown more piglet-directed behaviour than sows in crates, and this behaviour was mostly performed in the first two hours (Jarvis et al., 2004). Consequently, the risk of crushing might be higher in these first two hours (Weary et al., 1996).

The first days of lactation are also associated with prolonged periods of lying with an increase in frequency of postural changes and time spent standing as lactation progresses (Blackshaw et al., 1994; Valros et al., 2003). In the first three days sows in pens were lying down for approximately 20 hours per day (Danholt et al., 2011). Cronin et al. (1994) found that sows were lying laterally in approximately 75% of observations in the first 48 hours after farrowing regardless if they were housed in pens or crates. Similarly, Weary et al. (1996) showed that sows on average performed around 3 postural changes per hour on day 1-3 after farrowing and that this was not different between penned and crated sows. In contrast, Melisova et al. (2014) found more postural changes in penned sows compared to crated sows in the first 72 hours after birth of the first piglet, but the results did not show if this difference was mainly seen during or after farrowing. There was no difference in the number of times sows rolled from ventral to lateral in pens and crates in Weary et al (1996). This postural change however has been accounted for a considerable proportion of piglet deaths thus indicating that this type of roll is dangerous in relation to piglet crushing (Weary et al., 1996; Weary et al., 1998; Danholt et al., 2011).

One of the primary activities during lactation is suckling. According to Cronin and Smith (1992) there was no difference in the number of suckling bouts in pens or crates day 1-3 after farrowing (approximately 4-6 bouts in four hours). The average duration of rapid suckling grunts performed by the sows day 1-3 was longer for sows in pens compared to sows in crates (pens: 64.7 seconds, crates: 50.7 seconds) and the average duration of rapid suckling movements performed by the piglets day 1-3 was longer in pens than in crates (pens: 23 seconds, crates: 18 seconds). Another study of udder access in pens and crates on days 14 and 28 found that sows terminated more nursings in crates than in pens (pens: 46%, crates: 57%), and that this was caused by more frantic nursings in crates that involved more fighting between piglets (Pedersen et al., 2011b).

Physiological effects

In pigs, the response to a stressor such as confinement involves activation of the hypothalamic-pituitary axis (HPA) and the release of adrenocorticotropic hormone (ACTH), which stimulates the secretion of cortisol. In studies of HPA activity during nest building there was evidence of increased cortisol and ACTH concentrations in crated sows compared to penned sows which suggested increased stress when sows were confined before farrowing (Jarvis et al., 1997; Jarvis et al., 2001; Jarvis et al., 2002). As farrowing progressed the stress-inducing aspects of farrowing seemed greater than any effects of system (Lawrence et al., 1997). From day 1 to 5 after farrowing, sows in pens have been shown to have higher levels of saliva cortisol than sows in crates (pens: 19.9 ng/ml, crates: 13.2 ng/ml) (Oliviero et al., 2008). In Biensen et al. (1996), plasma cortisol levels were higher in pens than in crates from lactation day 1-21 (pens: 3.2 ng/ml, crates: 2.8 ng/ml). Another study found no effect of housing during the first weeks of lactation (Cronin et al., 1991). However, towards the end of lactation crated sows showed higher levels of cortisol than penned sows (pens: 4.0 nmol/l, crates:

5.6 nmol/l) (Cronin et al., 1991) as well as a higher cortisol response to a challenge test and increased cortisol/ACTH ratio compared to penned sows, suggesting that prolonged confinement induces stress (Jarvis et al., 2006).

To summarise, the literature suggests that confinement in farrowing crates affected both behaviour and physiology before farrowing, whereas the effect of housing system was diminished during farrowing and in the following first days of lactation. In addition, there were indications that prolonged confinement causes stress, and that suckling behaviour was affected as well. These results suggest that limiting the use of confinement to periods with prolonged lateral lying and little activity might decrease negative effects on sow welfare considerably. However, it is unknown how confinement affects sow behaviour if sows are restricted for a limited period of time and not throughout the period from placement in the farrowing unit to weaning.

Temporary confinement

The majority of research on alternative lactation housing compared traditional farrowing crates with various farrowing pens without any confinement (e.g. Blackshaw et al., 1994; Jarvis et al., 2001; Thodberg et al., 2002a). The biological needs of the sow for space and substrates during nest building are very different from the needs for a suitable lying area for the sow and protection for the piglets during lactation (Baxter et al., 2011a). In addition, the majority of piglet losses occur during the first days post farrowing (Marchant et al., 2000; KilBride et al., 2012), indicating that there is a period of a few days where confinement of the sow may be needed to prevent piglet crushing. Moustsen et al. (2013) studied piglet mortality in a combi-pen and the results suggested that confinement for four or seven days after farrowing reduced piglet mortality to a level that was comparable to that in crates.

Temporary confinement- meaning that confinement is used for a few days after farrowing, might be a way to improve piglet survival with minimal restrictions on the sow since sow behaviour is described by prolonged lateral lying and low level of activity in early lactation (Weary et al., 1996; Jarvis et al., 2004; Danholt et al., 2011). In this period of time, motivation to move around is diminished and the physical restriction imposed by use of confinement may not be conflicting with normal sow behaviour to the same extent as in other, more active periods. However, little research has been conducted on housing systems where sows can be confined temporarily to protect piglets. In addition, the approach to pen design in previous studies was to house sows in farrowing crates that could be opened when confinement was no longer needed (Weber, 2000; Moustsen et al., 2013). If confinement is only needed for a few days, the sow will be loose housed for the majority of the time in the farrowing unit. Therefore a more logical approach would be to incorporate an option of confinement into a pen that is designed for a loose housed sow. Designed pens seem to provide a good alternative to traditional farrowing crates when considering welfare and economic performance (Baxter et al., 2012; Pedersen et al., 2013), but evidence of consistently satisfactory results in commercial herds is needed. No commercial system, where a designed pen is fitted with an option for temporary confinement has been developed or studied. Development of a temporary confined system could improve the viability of housing systems where sows are allowed freedom of movement. Thus, the performance of systems using temporary confinement should be investigated and further studies are needed to elucidate how temporary confinement might affect the sows and the piglets.

OBJECTIVES AND HYPOTHESES

The overall objective of this thesis was to investigate piglet mortality in designed farrowing pens and the effects of temporary confinement on piglet mortality as well as on sow behaviour and physiology.

Specifically, the objectives of this thesis were to investigate piglet mortality of hyper-prolific sows housed in designed farrowing pens under commercial conditions and to investigate if farrowing progress and early piglet mortality was affected by confinement of sows from day 114 of gestation and during the first four days after farrowing. Furthermore, to study how sow behaviour, saliva cortisol and piglet mortality was affected by the use of temporary confinement in a designed farrowing pen.

The hypotheses were:

- Piglet mortality in designed farrowing pens are greater than in traditional farrowing crates in commercial herds
- Confinement of loose housed sows from day 114 of gestation and during the first four days of lactation prolongs farrowing duration and birth intervals, but decreases early piglet mortality compared to loose housed sows
- Confinement of loose housed sows in designed farrowing pens during the first four days of lactation decreases piglet mortality compared to loose housed sows
- Confinement of loose housed sows in designed farrowing pens during the first four days of lactation affects sow behaviour and increases saliva cortisol compared to loose housed sows

RESEARCH APPROACH

To compare piglet mortality in traditional farrowing crates and free farrowing pens, data was obtained from three piggeries that had both housing systems in their farrowing units and had been using the systems for more than one year. Data was collected over a two year period and piglet mortality was analysed in two periods: before litter equalisation and after litter equalisation.

To study effects of confinement from day 114 of gestation and during the first four lactation days on farrowing progress and early piglet mortality, a study was conducted in a commercial herd where farrowing pens were equipped with a swing-side crate. Sows were loose housed or confined from gestation day 114 to end of farrowing, and loose housed or confined for four days after farrowing, resulting in four treatments: loose-loose, loose-confined, confined-loose, and confined-confined.

The effects of temporary confinement in designed farrowing pens on piglet mortality, sow behaviour and saliva cortisol were studied in a newly built herd with SWAP pens (Sow Welfare And Piglet protection). Sows were housed according to three strategies of confinement: loose housed from entry to weaning, confined from the end of farrowing to day 4 after farrowing, or confined from day 114 of gestation to day 4 after farrowing.

OUTLINE OF THE THESIS

This thesis consists of a synopsis and four papers. The synopsis describes background and objectives of the thesis followed by a summary of materials and methods as well as results from the experimental studies. The results are related to existing scientific literature in the general discussion to provide the conclusions and the perspectives for pig production as well as further research. Following the synopsis is four papers presenting the results from the experimental studies in detail:

- Higher preweaning mortality in free farrowing pens compared with farrowing crates in three commercial pig farms. *Published in Animal.*
- Comparable farrowing progress in confined and loose housed hyper-prolific sows. *Published in Livestock Science.*
- Temporary confinement of loose housed hyper-prolific sows reduces piglet mortality. *Submitted for publication.*
- Confinement of sows in SWAP farrowing pens to day four of lactation influences sow behaviour and saliva cortisol. *Unpublished manuscript.*

MATERIALS AND METHODS

The following section contains an overview of the three experimental studies that were planned and carried out to test the hypotheses of the thesis. The first study investigated piglet mortality in free farrowing pens and traditional farrowing crates in three commercial herds in Denmark that had been using both systems for more than a year. Data for the first study was collected prior to the PhD project as part of another project developing a database of piglet mortality in herds with loose housed sows. The formulated hypothesis and the use of specific data to answer this hypothesis were conducted as part of the PhD project. The second study was carried out to study the effects of confinement from day 114 of gestation to day 4 after farrowing on farrowing progress and early piglet mortality. Finally, the third study investigated if piglet mortality was affected by confining sows in a pen for loose housed sows with an option of confinement from day 114 of gestation and for the first four days of lactation. Furthermore, the third study was carried out to study the effects of temporary confinement around farrowing on sow behaviour and saliva cortisol. Elaborate descriptions of materials and methods are presented in the papers (I-IV).

Study I (Paper I)

The study was conducted from 2010 to 2012 in three commercial piggeries; Herd A, Herd B and Herd C in Denmark with 400, 580, and 640 sows, respectively. All herds had traditional farrowing crates as the main housing for lactating sows and a number of Free Farrowing pens (FF-pens) that had been in use for at least one year when the data collection started.

Housing, animals and management

The FF-pens were based on the same layout (Figure 1) with 60% solid or drained (<10% void) floor and 40% slatted (>40% void) floor, a creep area adjacent to the inspection aisle, a sloping wall, piglet protection rails in the dunging area, a trough and drinker for the sow and a drinker for the piglets. The layout of the pens with farrowing crates was also similar in the three herds (Figure 2). There was 60% solid floor and 40% slatted floor, a farrowing crate where sows faced away from the inspection aisle, a trough and drinker for the sow, a creep area next to the trough and a separate drinker for the piglets. All creeps were fitted with a 150 W heat lamp in the adjustable cover.

Data was collected from 1,416 Danish Landrace × Danish Yorkshire sows and their litters and management procedures followed the normal procedures of the herds. Sows were randomly allocated to traditional farrowing crates or farrowing pens. Litters were equalised within 12-24 hours after farrowing, provided that all piglets had received colostrum. First parity litters were equalised to 14 piglets and older sows were equalised to 13 piglets. Surplus piglets were moved to nurse sows that were not part of the experiment. All piglets were injected with iron and tail docked and males were surgically castrated on day 3 or 4 after farrowing. If piglets were unable to survive to weaning they were humanely euthanized by blunt force trauma.

Records

The date of entry into pens or crates, parity of the sow, date of farrowing, number of live born and stillborn piglets and any obstetric aid during farrowing were recorded on a sow card. After farrowing the date of litter equalisation, the number of added or removed piglets were logged and piglets that died were recorded with a date and cause of death judged by the staff.

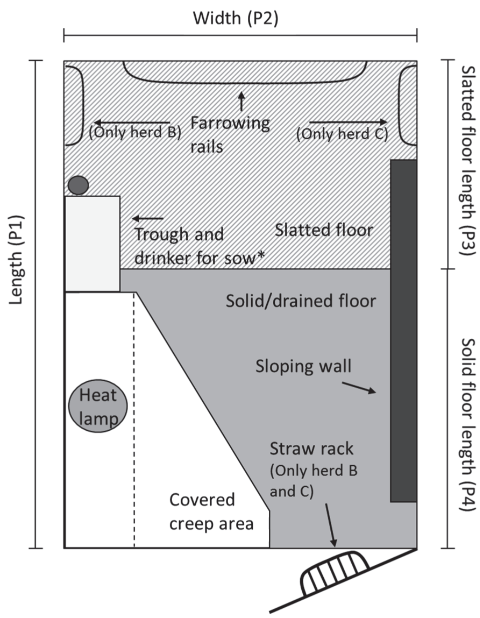

Figure 1. Layout of Free Farrowing pen (FF-pen) in Herd A, B and C. Dimensions: Herd A: P1 = 270 cm, P2 = 198 cm, P3 = 120 cm, P4 = 150 cm; Herd B: P1 = 280 cm, P2 = 185 cm, P3 = 160 cm, P4 = 120 cm; Herd C: P1 = 300 cm, P2 = 210 cm, P3 = 118 cm, P4 = 182 cm.

*In Herd A the trough was placed in the corner between P1 and P2.

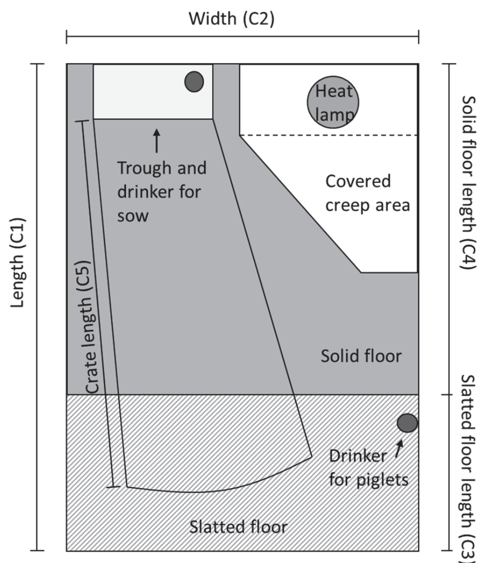

Figure 2. Layout of pen with farrowing crate in Herd A, B and C. Dimensions: Herd A: C1 = 245 cm, C2 = 140 cm, C3 = 95 cm, C4 = 150 cm, C5 = 195 cm; Herd B: C1 = 257 cm, C2 = 156 cm, C3 = 100 cm, C4 = 157 cm, C5 = 190 cm; Herd C: C1 = 260 cm, C2 = 156 cm, C3 = 100 cm, C4 = 160 cm, C5 = 200 cm.

Study II (Paper II)

This study was conducted in a commercial Danish piggery with 400 Danish Landrace x Danish Yorkshire sows. Sows were housed in group systems during mating and gestation, and moved to individual farrowing pens one week before expected farrowing.

Housing, animals and experimental design

The farrowing pens (Figure 3) were 5.3 m2, and had partly solid concrete floor and partly slatted floor (>40% void). All pens were equipped with a swing-side farrowing crate, a trough and drinker in front of the crate and a straw dispenser mounted on the crate. There was a covered creep area for the piglets with a 150 W heat lamp and sawdust as bedding next to the trough. Piglets had access to a separate feeder and drinker outside the creep area.

The study included 120 sows of parity 1 to 7. All sows were randomly allocated to one of the four treatment groups: confined-confined (CC), confined-loose (CL), loose-confined (LC) or loose-loose (LL). All sows were loose housed until day 113 of pregnancy. From day 114 until the end of farrowing (birth of the last piglet) CC and CL sows were confined in the swing-side crate and LL and LC sows continued to be loose housed. Thus, sows were either 'confined' or 'loose' before farrowing. For the first four days of lactation sows in CC and LC were confined in crates and sows in CL and LL were loose housed. From day 4 to day 7 after farrowing all sows were loose.

Management and records

Management routines and handling of sows and piglets were conducted in accordance with normal practices of the herd. All piglets were closed inside the creep at the first feeding of the sows after farrowing and piglets were split-suckled to ensure colostrum for all piglets. Litters were equalised within treatment by cross-fostering to 14 piglets at first parity sows and 13 piglets at older sows within 24 hours after farrowing. Surplus piglets were fostered to nurse sows outside the experiment.

Date and time of start and end of farrowing, live born, stillborn and any obstetric aid during farrowing was noted on a sow card. Date and time of litter equalisation and number of piglets the litter was equalised to was logged, as well as date and time of finding of any dead piglets and their cause of death. Dead piglets were subjected to post mortem examinations to assess cause of death. Sows were recorded on video cameras from day 114 of gestation to day 4 after farrowing. Time of expulsion of each piglet in a litter and whether or not the piglet was live born was registered from the video recordings.

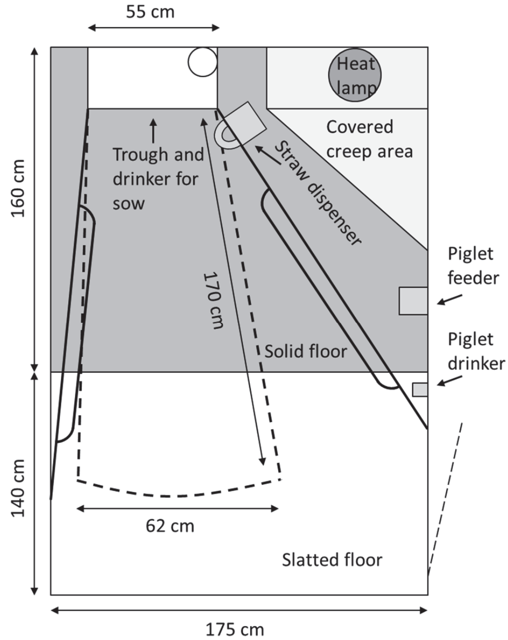

Figure 3. Illustration of pen design and dimensions for confined and loose housed sows. Solid lines represents housing of loose housed sows and the dashed lines represents housing of confined sows.

Study III (Paper III and IV)

A new design for a pen, where sows could be confined temporarily was developed (in collaboration with housing company Jyden) for study III and named SWAP (Sow Welfare And Piglet protection) pen. The design of the SWAP pen was based on the design of the Free Farrowing pen (Figure 1) used in study I, as the needs of the sow, the piglets and the producer are taken into consideration in that pen design. The principle behind the SWAP pen was to allow the sow as much freedom of movement as possible in the farrowing unit and only confine the sows for a short period in the first days after farrowing where the risk of piglet losses is greatest. Other commercially available systems, such as the pen design used in study II (Figure 3), are based on the principle of opening up a crate, meaning that pen design is based on a confined sow. In the SWAP pen, the idea is to use a pen designed for a loose housed sow as starting point (Start With A Pen) and then incorporate an option for temporary confinement by alternating the front of the creep to form a hinged swing-side that can be used to confine the sow.

Housing, experimental design and management

A Danish herd with 1,250 Danish Landrace × Danish Yorkshire sows that farrowed in weekly batches were used in this study. All sows were loose housed in the mating and gestation units and five days before expected farrowing they were placed in individual SWAP pens (Figure 4) in the farrowing unit. The SWAP pens (6.3 m2) were designed according to the size of a modern day sow with 60% solid floor and 40 % slatted floor (>40% void) and a creep area adjacent to the aisle. A trough and drinker for the sow and a separate drinker for the piglets were placed next to the creep, a sloping wall was fitted on the opposite side and there were farrowing rails in the dunging area. The front of the creep area was made up of a swing-side that folded out to serve as the temporary confinement against the sloped wall. On the gate (which was directly in front of the sow when confined) there was a straw rack and an additional trough and drinker for the sow.

The experimental design consisted of three treatments: loose-loose (LL), loose-confined (LC) and confined-confined (CC). In LL sows were loose housed from entry in the farrowing unit to weaning at four weeks. In LC sows were loose housed at entry until they finished farrowing. After farrowing the sows were confined for the first four days of lactation. In CC sows were loose housed at entry and confined from day 114 of gestation and for the first four days of lactation. Confinement was removed on day 4 in LC and CC and sows were loose housed to weaning.

Management practices followed the normal procedures of the herd. Piglets were inspected and handled the first day after farrowing (remove dry umbilical cords and administer antibiotics) and on day 3 (tail docking, administration of Bay cox, injection of iron/pain relief mixture and castration). Litters were equalised within treatments to 13-14 piglets per litter and surplus piglets were tagged and moved to a nurse sow housed according to the treatment the piglets originated from. For the first two days, piglets were closed inside the creep during morning and afternoon feeding.

Animals, records and post mortem examination

The study involved 1,125 sows of parity 1-4. Of these sows, 144 parity 1 and 2 sows took part in saliva sampling and heart rate measurements, and 60 sows were subsequently selected for behavioural registrations. All sow cards contained information on entry date, date and time of farrowing, number of live born and stillborn piglets and date and time of closing or opening the confinement. Equalised litter size and piglets added or removed from the litter were noted along with dead piglets. Dead piglets were subjected to post mortem examination to establish cause of death and contents of the stomach.

Behavioural observations and saliva cortisol

Video recording commenced on day 113 of gestation and ended day 5 after farrowing. The date and time of last born piglet was noted and the date of the first time interval after all piglets were born, was denoted day 0. Sow behaviour was observed on day 1, 2 and 3 in the time intervals 4:00-6:00, 10:00-12:00, 16:00-18:00 and 22:00-24:00. Sow posture was recorded when sows changed posture and along with use of the sloping wall in lying down events. Postural changes were subsequently divided into lying down (lying down from standing), minor lying down (lying down from sitting), getting up (from lying to standing), minor getting up (from lying to sitting and from sitting to standing), rolling (movements between lying ventrally and lying laterally), rolling ventral to lateral, and rolling lateral to ventral. Nursing behaviour was recorded with start of nursing, end of nursing and whether the nursing was terminated by the sow or by the piglets.

Saliva samples were collected three times a day from day 114 of gestation to day 4 after farrowing and concentration of cortisol was determined by enzymeimmunoassay of a pooled daily sample.

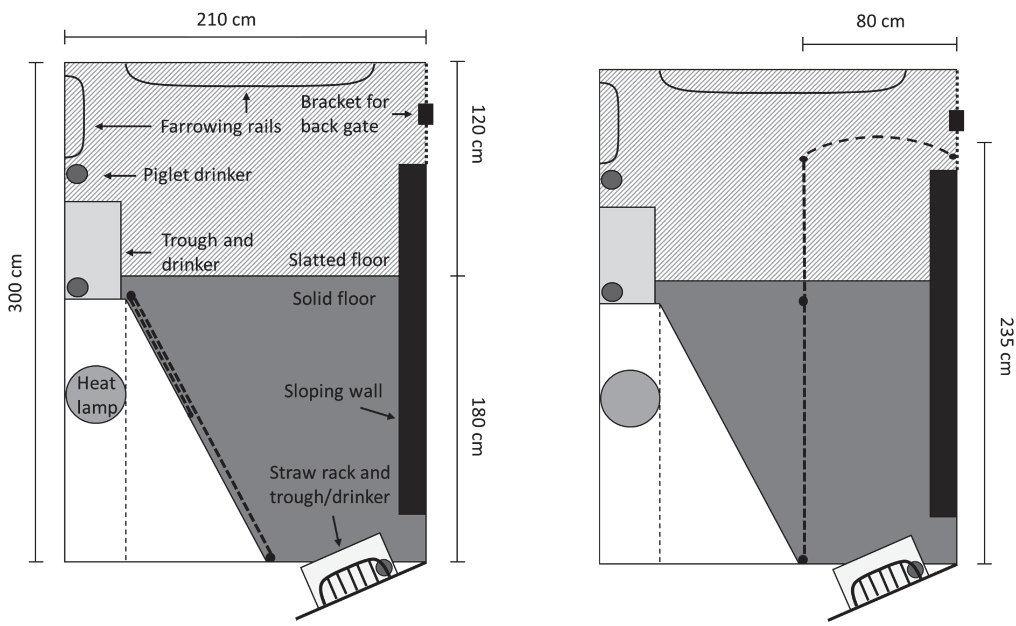

Figure 4. Illustration of dimensions and design of SWAP (Sow Welfare and Piglet protection) farrowing pen when confinement is not in use (left) and when confinement is in use (right).

Figure 5. Farrowing crate used in study I.

Figure 6. Free Farrowing pen used in study I.

Figure 7. Pen used in study II with open swing-side crate.

Figure 8. Pen used in study II with closed swing-side crate.

Figure 9. SWAP pen used in study III when the sow is loose housed.

Figure 10. SWAP pen used in study III when the sow is in temporary confinement.

RESULTS

This section summarizes the main results obtained in the three experimental studies. The detailed description of the results can be found in each of the papers (I-V).

Study I (Paper I)
Data for comparison of piglet mortality in farrowing pens and farrowing crates were collected from 1,416 farrowings, of which 48 were removed from the analyses. The results are based on the remaining 735 farrowings in pens (Herd A: 275, Herd B: 238, Herd C: 222) and 633 farrowings in crates (Herd A: 68, Herd B: 268, Herd C: 297).

Piglet mortality before litter equalisation
Before litter equalisation, the overall piglet mortality ((stillborn + live-born deaths)/total born) was higher in pens compared with crates (pens: 13.7%, crates: 11.8%; $P < 0.001$). The proportion of sows with high mortality (>11%) before equalisation was also higher in pens compared with crates in Herd B (pens: 66%, crates: 52%; $P = 0.001$), but not in Herd A (pens: 58%, crates: 47%; $P = 0.11$) and Herd C (pens: 45%, crates: 44%; $P = 0.77$).

Piglet mortality after litter equalisation
From equalisation to weaning mortality was higher in pens than in crates in all three herds, but the scale of the difference was not consistent (housing × herd: $P = 0.019$). The difference was greater in Herd A (pens: 16.7%, crates: 8.2%) compared to Herd B (pens: 11.4%, crates: 7.0%) and Herd C (pens: 7.1%, crates: 5.2%). The majority of piglet deaths happened in the first week after farrowing where mortality in pens was greater than in crates in Herd A (pens: 11.3%, crates: 5.4%; $P < 0.001$) as well as in Herd B (pens: 7.7 %, crates: 4.4%; $P < 0.001$) and Herd C (pens: 5.3%, crates: 4.0%; $P = 0.013$). Mortality was higher in pens than in crates in the second week (pens: 1.8%, crates: 1.0%; $P < 0001$) and in the third and fourth week (pens: 1.2%, crates: 0.8%; $P = 0.009$). The proportion of sows with high mortality after equalisation (>7%) was higher in pens than crates in Herd A (pens: 77%, crates: 62%; $P = 0.012$) and Herd B (pens: 74%, crates: 51%; $P < 0.001$), but not in Herd C (pens: 52%, crates: 46%; $P = 0.18$). Mortality increased with increasing parity of the sows both before ($P < 0.001$) and after litter equalisation ($P < 0.001$). Moreover, increasing litter size increased mortality before equalisation ($P < 0.001$) and mortality after equalisation was higher when equalised litter size increased ($P < 0001$).

Study II (Paper II)

Data used to study the effects of confinement from day 114 of gestation to day 4 after farrowing on farrowing progress and piglet mortality was obtained from 120 sows. Two sows were confined too early and the results are therefore based on records from 30 sows in CC, 32 sows in CL, 28 sows in LC and 30 sows in LL.

Farrowing progress

Confinement before and during farrowing (CC and CL) did not affect the number of total born piglets ($P = 0.69$) live born piglets ($P = 0.83$) or stillborn piglets ($P = 0.68$) compared to sows that were loose housed before and during farrowing (LC and LL). Farrowing duration also did not differ between confined and loose housed sows (confined: 462 min, loose: 394 min; $P = 0.26$) and neither did birth interval (confined: 23 min, loose: 21 min; $P = 0.25$). Birth interval was shorter for live born piglets than for stillborn piglets (live born: 15 min, stillborn: 30 min; $P < 0.001$). For the loose housed sows, the number of stillborn piglets and live born mortality before equalisation increased with increasing farrowing duration ($P < 0.05$), but this pattern was not seen for the confined sows. Loose housed sows with short farrowings (< 5 hours) tended ($P = 0.06$) to have fewer stillborn piglets than confined sows with short farrowings. However, loose housed sows with medium (5-9 hours) or long (> 9 hours) farrowings had higher live born mortality before equalisation ($P < 0.05$) than confined sows with similar farrowing durations. Sows of parity 1-2 had shorter farrowing duration than sows of parity 3 or more (parity 1-2: 301 min, parity 3+: 577 min; $P < 0.001$).

Piglet mortality

Before litter equalisation live born mortality in LL (11.3%) was higher than in CC (5.0%), CL (6.6%) and LC (5.7%) ($P < 0.001$). From equalisation to day 4, mortality in LC (3.2%) was reduced compared to mortality in LL (7.5%; $P < 0.05$) and mortality in CC (5.0%) was reduced compared to CL (9.0%; $P < 0.05$). Mortality in LC was not different from mortality in CC and mortality in CL was not different from mortality in LL. From day 4 to day 7 there was a tendency ($P = 0.10$) for sows that were confined after farrowing (CC and LC) to have more dead piglets than sows that had been loose housed after farrowing (CL and LL). Sows of parity 1-2 had lower mortality before equalisation (parity 1-2: 4.2%, parity 3+: 10.9%; $P < 0.001$), from equalisation to day 4 (parity 1-2: 3.8%, parity 3+: 8.6%; $P < 0.001$) and from day 4 to day 7 (parity 1-2: 2.4%, parity 3+: 4.4%: $P = 0.02$) compared to sows of parity 3 or more.

Study III (Paper III and IV)

To study the effects of temporary confinement in designed pens on piglet mortality data was based on 58, 56 and 59 batches in LL, LC and CC respectively. Records from 131 sows were excluded from the analyses of piglet mortality on sow level due to insufficient data quality. Data used to study sow behaviour included observations of 58 sows and effects on saliva cortisol were based on samples from 143 sows.

Production systems

There was a similar number of farrowings per batch in the three treatments ($P = 0.10$) and the number of total born piglets per batch did not differ between treatments ($P = 0.29$). Total mortality ((stillborn + liveborn deaths)/total born) was 22.1% in CC and this was lower ($P < 0.001$) than in LL (26.0%) and in LC (25.4%). Live born mortality (live born deaths/live born) followed the same pattern with greater mortality in LL (21.4%) and LC (21.4%) than in CC (17.9%; $P < 0.001$). There was no difference in the proportion of stillborn piglets ($P = 0.21$) in the three treatments but a larger percentage (of total born) piglets were crushed in LL (10.7%) compared to LC (9.7%; $P = 0.03$), which again was more than in CC (7.8%; $P < 0.001$).

Sow performance

Sows in LL had fewer live born piglets than sows in LC and CC (LL: 16.6 piglets, LC: 17.1 piglets, CC: 17.0 piglets, $P = 0.01$), and sows in LL had more stillborn piglets per litter than sows in LC ($P = 0.027$) and CC ($P = 0.016$). Before litter equalisation live born mortality was greater in LL (7.5%) and LC (7.0%) than in CC (3.7%; $P < 0.001$). Concordantly, a larger percentage of sows in CC had low mortality before equalisation (84.9%) compared to the percentage in LL (66.0%) and LC (67.3%) ($P < 0.001$). From equalisation to day 4, mortality in LL (7.6%) was higher than in LC (6.7%; $P < 0.05$), which was higher than mortality in CC (5.6%; $P = 0.002$). Sows in LC and CC had higher mortality from day 4 to weaning (LC: 6.9%, CC: 6.6%) than sows in LL (5.6%; $P < 0.05$). Calculating the percentage of sows with high mortality after equalisation showed that a greater percentage of sows in CC (79.3%) had low mortality in comparison with 70.1% of sows in LL and 73.8% of sows in LC ($P = 0.002$). Sows of parity 1 had lower mortality from equalisation to day 4 than sows of parity 2 (Parity 1: 5.4 %, parity 2: 6.9%, $P < 0.05$) and sows of parity 3 or more had higher mortality than sows of parity 2 (parity 3+: 7.9%, $P < 0.05$).

Sow behaviour

Sows spent most of the observed 2-hour intervals lying laterally; 100-120 min was spent in lateral position on day 1 and 80-120 min on day 3. Sows spent more time standing during the day than the night but the diurnal pattern differed between the treatments ($P < 0.01$). Time spent lying lateral was similar across treatments ($P = 0.66$), but sows in CC spent more time sitting on day 3 than LC and LL sows ($P \leq 0.001$). The frequency of postural changes in a two hour interval was less than 10 on day 1 and less than 15 on day 3. The frequency of postural changes followed a diurnal pattern that differed between treatments ($P = 0.02$) and this pattern became more pronounced over the three observational days ($P = 0.03$). Sows had more postural changes during daytime intervals (10:00-12:00 and 16:00-18:00) compared to night-time intervals (4:00-6:00 and 22:00-24:00) ($P < 0.05$) but in LL the frequency during the 16:00-18:00 interval was higher than during the 10:00-12:00 interval ($P < 0.001$). Sows in LL were getting up and lying down more often than sows in LC and CC ($P < 0.05$). Rolling frequency also followed a diurnal pattern with more rolling during daytime intervals than night-time intervals ($P < 0.05$) and rolling increased over the three observational days in all treatments, but more so in LL compared to LC and CC ($P < 0.001$).

In LL and LC there were more nursing bouts on day 1 than on day 2 and 3 ($P < 0.01$), whereas nursing frequency in CC did not differ between the days. In addition, sows in LL had more nursings than sows in LC on day 1 ($P < 0.001$), and more nursings than sows in CC on all three days ($P < 0.05$). Duration of nursing bouts decreased from day 1 to day 2 in all treatments ($P < 0.05$), and further to day 3 in LL ($P < 0.001$) but not in LC and CC. The duration of potentially successful nursing bouts did however not differ between treatments ($P = 0.92$). Sows in LL terminated more nursings on day 3 than on day 1 ($P < 0.001$), whereas sows in LC and CC terminated an equal number of nursings on the three days ($P > 0.05$). As a consequence, sows in LL terminated more nursings than LC and CC sows on day 3 ($P \leq 0.001$).

Saliva cortisol concentrations

Saliva cortisol developed differently from two days before farrowing to day 4 after farrowing in the three treatments ($P < 0.001$). Sows in LL displayed numerically higher cortisol levels than LC, which was numerically higher than cortisol levels in CC. Sows in LL differed from LC sows on days -1, 1, and 2 ($P < 0.05$) and from CC sows from the day before farrowing to day 3 after farrowing ($P < 0.01$). Sows in LC had higher cortisol levels compared to CC sows on day 0 (farrowing) and day 1 ($P < 0.05$). Sows of parity 2 had higher level of saliva cortisol concentrations than sows of parity 1 on day 0 and 1 ($P \leq 0.01$).

DISCUSSION

The results obtained in the experimental studies are discussed in this section in relation to the proposed hypotheses. The first hypothesis; ‘Piglet mortality in designed farrowing pens is greater than in traditional farrowing crates in commercial herds’ was addressed in study I. The idea of temporary confinement was subsequently investigated in study II and study III to provide answers to the second hypothesis; ‘Confinement of loose housed sows from day 114 of gestation and during the first four days of lactation prolongs farrowing duration and birth intervals, but decreases early piglet mortality compared to loose housed sows’, the third hypothesis; ‘Confinement of loose housed sows in designed farrowing pens during the first four days of lactation decreases piglet mortality compared to loose housed sows’ as well as the fourth hypothesis; ‘Confinement of loose housed sows in designed farrowing pens during the first four days of lactation affects sow behaviour and increases saliva cortisol compared to loose housed sows’.

All studies in this thesis were conducted in commercial herds. The advantage of conducting experiments in commercial settings is that the obtained results are more robust and applicable to other herds compared to results that have been obtained under very controlled conditions. This does however also impose a number of limitations on the experiments. Although Danish farmers generally keep good records of piglet mortality etc., experimental registrations require a level of accuracy that can be hard to meet, especially as the main focus of the farmers and their staff is likely on their task at hand and not necessarily the experimental part of their work. In addition, procedures such as opening and closing of confinement are restricted to happen during work hours (daytime) when staff are present in the herd. In the studies conducted in this thesis, all registrations that were done in herds were checked continuously by trained technicians to ensure the quality of the data. Conducting research in commercial setting also influences the possibilities of sampling. Invasive procedures such as catheterization of sows for blood sampling are extensive whereas saliva sampling is a relatively easy obtainable alternative that also provides an opportunity to use a larger sample size. The use of non-invasive methods also complies with good conduct of research as it imposes little harm to the animals.

Piglet mortality

Piglet mortality was addressed in the first, second and third hypotheses and were thus studied in all three experiments. Achieving consistent levels of high performance, specifically low piglet mortality, is crucial for the success of any type of farrowing system.

Pens vs. crates

It was established that piglet mortality in designed farrowing pens was greater than what was achieved in traditional crates in three different commercial herds. Because piglet mortality was analysed separately before and after litter equalisation, the absolute levels of mortality are difficult to relate to other studies. However, it is noteworthy that mortality in pens before equalisation (13.7%) was similar to levels of live born mortality found by Weber et al. (2007) (13-14%) and Andersen et al. (2007) (15.2%). This suggests that live born mortality in pens study I was higher than previous reported levels in pens.

Studies comparing piglet mortality in loose housed and crated systems are somewhat inconsistent as some have found similar levels of piglet mortality in pens and crates (Cronin et al., 2000; Weber et al., 2007; KilBride et al., 2012) whereas others have found lower mortality rates in crates than pens (Blackshaw et al., 1994; Marchant et al., 2000). The latter two were based on rather small sample size, and could be influenced by a large degree of individual sow variation in piglet crushing (Jarvis et al., 2005). On the other hand, to compare populations like Weber et al. (2007) and KilBride et al. (2012) the samples need to be similar. In 1997 it was decided in Switzerland that sows should be able to turn around in the farrowing pen at all times, but in a transition period until 2007 crates could still be used. When Weber et al. (2007) compared herds with crated sows with herds with loose systems crated sows were possibly housed in older systems than the loose housed sows, which might influence the production. In Kilbride et al. (2012) it was estimated that they needed 50 farms for each of four systems studied but the study only included 112 farms in total where 15 had loose housed sows indoors. Moreover, comparing herds with pens and herds with crates does not necessarily explain if confinement in crates affects the performance in the individual herds as herd comparisons not only are a reflection of the housing system, but also of the management in the herds. The results from study I showed that in one of the herds (Herd C), piglet mortality was at a level that was comparable to the level in crates in the other two herds (Herd A and Herd B), but a lower level of piglet mortality was achieved if sows were housed in crates. Similar to study I Cronin et al. (2000) compared pens and crates that were managed equally, but the conclusions are contradicting each other as Cronin et al. (2000) did not detect any difference. Genetic improvements have increased litter size markedly in Denmark (Baxter et al., 2013) and the unfavourable relationship between larger litter size and increased piglet mortality (Roehe and Kalm, 2000; Pedersen et al., 2006) indicates that a higher preweaning mortality can be expected in studies with larger litter sizes. The effects of litter size were also evident in study I where total born and equalised litter size influenced piglet mortality, and the implications of larger litters will be discussed later in this section. Piglet mortality was reduced in crates all four weeks of lactation, but as seen in previous studies (Marchant et al., 2000; KilBride et al., 2012), the majority of piglet deaths in study I happened during the piglets' first week of life. This supported the idea of using confinement for a short period of time in early lactation to decrease piglet mortality in loose housed systems.

Temporary confinement

In both study II and III there was a benefit of confining sows for four days of lactation compared to loose housed sows as piglet mortality was reduced. This is in accordance with previously reported effects of temporary confinement (Moustsen et al., 2013). However, the results were not all in agreement between the two studies. Results from study II suggested that compared to loose housed sows, confinement from the end of farrowing to day 4 after farrowing decreased live born mortality before equalisation as well as mortality form equalisation to day 4. However, no further reduction was seen if sows were confined from two days before expected farrowing to day 4. The results from study III suggested a different pattern. Sows that were confined from the end of farrowing to day 4 had lower mortality from equalisation to day 4. However, there was no reduction before equalisation and total preweaning mortality was not different from the loose housed sows. Confinement from two days before expected farrowing to day 4 reduced mortality before equalisation as well as from equalisation to day 4 and - as a consequence - live born and total piglet mortality was reduced. The effect of confinement after farrowing that was found in study II was thus not replicated in study III. Although strategies of confinement were similar in the two studies there were a number of differences between them that might explain why the obtained results differed. As previously mentioned, sows in study II were parity 1 to 7 whereas sows in study III were parity 1 to 4. In accordance with other studies (Weary et al., 1998; Jarvis et al., 2005), both studies showed that piglet mortality increased when sows got older and that the age distribution might consequently be accountable for some of the discrepancies between results. Furthermore, the restriction in study II were more severe than in study III as pens in study II had farrowing rails that could move up and down on the swing-sides of the crate. Moreover, although guidelines for time of cross fostering were similar, it cannot be ruled out that the time from end of farrowing to litter equalisation was of importance. It should also be noted that sows in study II had been in confinement during prior farrowings and lactations and were thus used to the confinement. Sows in study III had less experience with confinement and their behaviour might have been influenced by this. Results from study III depict piglet mortality from more than 600 sows in each treatment, whereas study II was conducted with 30 sows in each treatment as that study was dimensioned to compare differences in farrowing progress. The individual sow variation was thus much less influential in study III whereas poor or good performance of individual sows could have had more influence on the results in study II.

Both studies suggested that confinement decreased the risk of piglet crushing. This is in agreement with other studies reporting an increased risk of crushing in loose housed sows (Marchant et al., 2000; Jarvis et al., 2005; Wechsler and Weber, 2007). In addition, a large proportion of dead piglets in study III had empty or little stomach contents. Nutritional status has previously been identified as a predisposing factor for crushing as large proportions of crushed piglets did not have any milk in their stomachs (Pedersen et al., 2006; Andersen et al., 2011; Hales et al., 2013).

The results from study II as well as study III, suggested that confinement from before farrowing to day 4 reduced piglet mortality. In addition, there was a tendency for increased mortality when sows were no longer in confinement in study II as well as in study III. The suboptimal pen design in study II might have caused sows to lie down without support, which is more dangerous for the piglets than if the sows lie down against a wall (Marchant et al., 2001). In study III there was a sloped wall to support lying down movements (Damm et al., 2006), but this did not seem to be enough to prevent increased mortality after the confined period. It should be noted that due to lower mortality to day 4, the number of piglets at risk of crushing was greater if sows had been confined for four days, and this might explain the higher mortality (Weary et al., 1998). It is however important to investigate why this increase in mortality occurs to see if it can be prevented or reduced. For instance, it might be beneficial to put the piglets in the creep for a period of time while the sow gets used to being loose, or, considering the diurnal pattern of activity shown in study III, it may be beneficial to remove the confinement within a time frame where the sow is expected to be active or inactive.

High vs. low mortality sows

There was a proportion of sows that did not perform well in relation to piglet mortality, regardless of housing system. In study I this proportion was larger in the pens than in crates and in study III the proportion was greater amongst sows that were loose housed before and during farrowing than sows that were confined before farrowing. The proportion of sows that did not perform well seemed in general to be larger in study I than in study III, but this could be attributed to differences in definitions of high and low mortality. In study I the definitions were mortality percentages based on the levels of high mortality in crates whereas the definitions of high mortality in study III were based on an absolute number of dead piglets. This latter approach was more applicable if herds wanted to use this information to select sows for nurse sows, slaughter etc. In addition, sows in study III were younger (parity 1-

4) than sows in study I (parity 1-7) and due to the negative influence of increased parity on piglet crushing (Jarvis et al., 2005), a large proportion of young sows was expected to yield lower piglet mortality in general. Jarvis et al. (2005) furthermore showed a high degree of variation in piglet crushing in pens but at the same time consistency in piglet crushing over parities. Sows with high mortality and sows with low mortality may display different behavioural patterns (Valros et al., 2003; Johnson et al., 2007). Studying behavioural differences between high and low mortality sows was outside the scope of this thesis but it would be very relevant to look further into identification of sows that can or cannot perform well in a loose housed system.

Effects of temporary confinement on sows

The effects of temporary confinement on sow behaviour and physiology were addressed in the second and fourth hypotheses. If temporary confinement served as a means to decrease piglet mortality without imposing detrimental restrictions on the sows, it could be a way to improve viability of loose housed systems.

Farrowing progress

Results from study II showed that confinement from day 114 of gestation had no influence on farrowing duration or birth interval and that farrowing duration was generally longer than what has been reported in existing literature. Baxter and Petherick (1980) suggested that confinement in crates was stress-inducing because sows were prevented from performing nest building behaviour, and that this could lead to prolonged duration of farrowing and increase the risk of stillbirth. Studies have shown that sows in traditional crates experience increased stress around farrowing compared to sows in pens (Jarvis et al., 1997; Jarvis et al., 2001), but the results on farrowing duration are inconsistent across studies. Oliviero et al. (2008) found longer duration of farrowing and birth intervals in crates than in pens, whereas Thodberg et al. (2002a) showed that housing affected gilts but not sows of parity 2. In accordance with results from study II, Jarvis et al. (2004) found no effect of housing on farrowing duration or birth intervals. An effect of confinement on farrowing duration could be confounded by an effect of access to nest building materials in the different studies. Sows that had access to a variety of nest building materials prior to farrowing had increased oxytocin concentrations in the last three days before farrowing, indicating a relation between availability of nesting materials and circulating oxytocin (Yun et al., 2013). In addition, provision of straw has been found to influence timing and quantity of nest building behaviour as well as the duration of the first part of farrowing (Thodberg et al., 1999). In study II all sows had permanent access to a dispenser with finely chopped straw and they were provided straw once a day in increasing amounts as they approached expected farrowing. Thus, the results found in this thesis were based on the restriction of available space rather than differences in the available nesting materials and this restriction did not seem to influence the sows. However, there is also evidence that gilts and sows respond differently to housing environment (Thodberg et al., 2002a; Pedersen and Jensen, 2008) and parity of the sows could also explain why results differed across studies.

Prolonged farrowing duration has previously been related to stillbirth (Canario et al., 2006; Vanderhaeghe et al., 2013), but this effect was only seen in sows that were loose housed before farrowing. Moreover, the results in study II suggested that prolonged duration of farrowing influenced the number of live born piglets that died before equalisation if sows were loose housed before farrowing, but not in the sows that were confined before farrowing. Accordingly, Malmkvist et al. (2006) found a similar relation between duration of farrowing and live born mortality. Consequences of prolonged farrowing duration include greater risk of asphyxiation that has a negative influence on the viability of the piglets (Herpin et al., 1996). The process of birth has also been related to piglet mortality in that being born late in the birth order was shown to have a negative effect on postnatal survivability of piglets (Tuchscherer et al., 2000; Baxter et al., 2008). Decreased viability can leave the piglets more susceptible to crushing and this might be more detrimental for piglet survival in a loose housed system where piglets are less protected than in a confined system.

Sow postures

Regardless of treatment, sows displayed an inactive behavioural pattern after farrowing especially on day 1 and 2. They were on average lying down laterally in up to 80-120 min of the two hour observational period and postural changes occurred less than 12 times in an observational period. Sows that were in confinement after farrowing had fewer postural changes than loose housed sows- partly because confinement, as expected, seemed to prevent rolling movements.

A low frequency of postural changes can indicate less restlessness and more comfortable sows, but few postural changes can also mean that sows are becoming inactive (Harris and Gonyou, 1998; Pedersen et al., 2007). Considering that the confined sows in study III had fewer postural changes and at the same time spent less time standing could indicate that they were becoming inactive. However, the treatment differences in postural changes were due to differences in the diurnal pattern where loose housed sows displayed a greater increase in daily activity than the confined sows, and sows spent equal amounts of time in lateral (and ventral) positions. If confined sows were becoming more passive they would be expected to spend more time in lateral position than the loose housed sows and this was not the case. In addition, there was a general increase in postural changes and time standing from day 1 to day 3, indicating that all sows became more active over the three days, which is consistent with a previous study on sow behaviour the first days after farrowing (Weary et al., 1996).

The observed differences in postural changes were partly set off by differences in rolling movements as loose housed sows performed more rolling than confined sows- especially on day 2 and 3. Rolling is associated with high risk of crushing and rolling from the udder to the side is more dangerous than rolling onto the udder (Weary et al., 1996; Marchant et al., 2001; Danholt et al., 2011). The results on piglet mortality in study III showed that fewer piglets died from crushing when sows were confined for four days- this could be due to the prevention of rolling when sows were confined. In addition, rolling from the udder to the side in the open of a pen is considered more dangerous than rolling with the back against a wall (protected rolling) (Danholt et al., 2011). Due to the design of the confinement where sows were placed next to the sloped wall, it is likely that a larger proportion of rolls was conducted with the back against the wall and could be considered to be 'protected'. Rolling behaviour developed differently in sows that were confined after farrowing and sows that were confined before farrowing, in that rolling frequency increased from day 1 to day 2 when sows were confined after farrowing but not if sows were confined before farrowing. This indicates that confinement before farrowing affects the behavioural pattern differently than confinement after farrowing, which could be because sows that are confined before farrowing have gotten used to the restrictions of the confinement whereas the sows that are confined after farrowing have not adapted to the restrictions of confinement. In addition, confinement before farrowing resulted in prolonged duration of sitting on day 3, which could mean that sows that were confined before farrowing were frustrated and prevented from performing behaviours they were motivated to perform (Jarvis et al., 2004).

Nursing bouts

Nursing frequency differed between the loose housed sows and the confined sows, and more so if sows had been confined from before farrowing in that nursing frequency was decreased on all days if sows were confined before farrowing compared to the loose housed sows. In addition, loose housed sows terminated more nursings on day 3. According to Bozdechova et al. (2014), sows were more likely to change posture when the number of piglets fighting and screaming after milk ejection increased on day 2 after farrowing. Piglet behaviour and the establishment of teat order may thus be involved in the differences in nursing patterns. A higher number of teat fights due to restricted udder access in crates was also the reason why Pedersen et al. (2011b) suggested that sows in crates terminate more nursings than sows in pens. The differences in the number of nursings terminated by the sow are possibly related to the prevention of rolling behaviour as this is one way for the sow to terminated nursings.

Thodberg et al. (2002b) suggested that penned sows were more in control of nursings and hence terminated more nursings than crated sows. The fact that the number of nursings terminated by the sow increased over the days in the loose housed sows, but not in the confined sows, supports this suggestion of increased control in loose housed sows.

The fingers at the bottom bar of the confinement in SWAP pens could have restricted access to the udder by physically preventing the piglets from getting access and thus caused more disturbances at the udder during nursing. Considering that piglets were only three days old, and hence still rather small, it was not likely a major restriction. In addition, if differences were caused by the presence of the fingers, effects in the confined treatments would be similar and the frequency of nursings in sows that were confined after farrowing was not affected to a level that was different from the loose housed sows on day 2 and 3. Nursing frequency seemed thus to be affected if sows had been confined before farrowing. According to Yun et al. (2013) the provision of space prior to farrowing led to decreased duration of successful nursings on day 3 and 6, but they did not find any differences in circulating oxytocin or prolactin day 1 to 7. Nursing duration did not differ between treatments in study III, but this could be influenced by a less detailed definition of successful nursing as well as the time of observation.

The video recordings in study III did not allow for very detailed study of nursing behaviour, but considering the results it would be relevant to further investigate the effects of confinement on nursing behaviour in the early days of lactation.

Physiology

It was hypothesised that confinement would increase saliva cortisol concentrations compared to the loose housed sows but this hypothesis could not be confirmed. Saliva cortisol concentrations increased around farrowing for the sows that were loose housed before farrowing, and then decreased after farrowing. Sows that were confined before farrowing displayed a smaller increase in saliva cortisol at farrowing and cortisol concentration remained at similar, much lower level than the other treatments after farrowing. Oliviero et al. (2008) depicted an increase in saliva cortisol for both penned and crated sows at farrowing, but cortisol remained elevated for 5 days after farrowing for the crated and not the penned sows. Cronin et al. (1991) also did not find any effects of housing on day 1 after farrowing however they also did not find any effects of housing on day 7. Results from other studies have also suggested that cortisol concentration was unaffected by housing around farrowing, possibly because the endocrine changes associated with farrowing overruled any response to other stressors (Lawrence et al., 1997; Jarvis et al., 2006). The results from study III suggested that there was an increased stress response leading up to farrowing when sows were loose housed, but confinement before farrowing seemed to dampen this increase in cortisol concentration around farrowing. Although the pens and the option of confinement in study III differs somewhat from housing systems used in other studies, there is no apparent explanation why saliva cortisol concentrations did not increase in the same way in the confined sows as it did in the loose housed sows. Studies have demonstrated that states of acute stress may occur the day after sows are moved to farrowing crates, but chronic stress did not occur until late in lactation (Cronin et al., 1991; Jarvis et al., 2006), indicating that confinement for a few days would not affect HPA activity. However, in light of the findings in study III it would be relevant to look further into the physiological response of sows to different strategies of temporary confinement.

Because farrowing was expected to overrule any effects of housing system and since farrowing progress seemed unaffected by confinement in study II, behavioural analyses were focused on day 1 to day 3 after farrowing. Any responses to the physical restriction imposed by confinement were expected to be more evident as activity increased after farrowing. The behavioural analyses suggested that an effect of the physical restriction was more pronounced on day 3 compared to day 1. However, there was no indication from results on saliva cortisol that the restriction imposed a state of physiological stress in the confined sows as the level of cortisol remained lower than the loose housed sows on day 3. The response in saliva cortisol in the first days after farrowing seemed rather to be influenced by the surge appearing around farrowing.

Influence of parity and litter size

In all three studies there was an effect of parity on piglet mortality showing that younger sows had lower mortality than older sows. It is well described in the literature that increased parity has a negative effect on piglet mortality and that the rate of crushing seems to increase with increasing parity (Weary et al., 1998; Roehe and Kalm, 2000; Jarvis et al., 2005). Increased parity was associated with larger litter size in all three studies and effects of parity might also be a reflection of the relation between parity and litter size (Weary et al., 1998). Larger litter size has been established as risk factor for increased mortality in previous studies (Roehe and Kalm, 2000; Pedersen et al., 2006). Accordingly, increasing litter size was shown to have a negative impact on live born mortality before equalisation in study I and study III, and increasing size of the equalised litter was related to increased mortality after equalisation in both studies as well. Reported consequences of increasing litter size that are likely to influence the risk of mortality include increased risk of asphyxia due to longer farrowing duration (Herpin et al., 1996), decreased piglet birth weight (Wolf et al., 2008), and increased teat competition (Andersen et al., 2011). In both study I and III older sows were equalised to fewer piglets than first parity sows and yet mortality was higher for the older sows. This indicates that it is not only a larger number of piglets born that is increasing mortality in older sows. Older sows may be larger in size and heavier than younger sows (Moustsen et al., 2011) and this could potentially influence the frequency of behaviours and the way they perform different movements. The behavioural analyses of study III only showed a few effects of parity, such as lower frequency of rolling in parity 2 sows compared to parity 1 sows. However, these analyses only included (young) sows of parity 1 and 2 and to properly investigate the influence of parity on behaviour, a study should include older sows as well. Research has also shown that increased sow parity is related to decreased mean birth weight of the litter as well as increased variation in birth weight in a litter (Quesnel et al., 2008), possibly through the relation with increased litter size as well. In addition, older sows have been found to be less responsive to piglets (Hutson et al., 1992; Held et al., 2006). The results from study III furthermore suggested that parity 2 sows had increased concentration of cortisol around farrowing compared to parity 1 sows. Accordingly, Yun et al. (2013) found increased prolactin concentrations in sows of parity 3-4 compared to sows of parity 1 regardless of environment around nest building. Thus, there are indications that the behaviour as well as the physiological state of the sows was influenced by parity and that regardless of environment, older sows may experience increased level of stress compared to younger sows.

Pen design

The pens used in study II (Figure 8) were equipped with swing side crates that were very similar to traditional farrowing crates. Housing sows in confinement in this system is comparable to housing sows in traditional farrowing crates. However, the option of confinement in the SWAP pens used in study III (Figure 10) is not as similar to traditional farrowing crates. A traditional farrowing crate is typically made up of metal bars on each side of the sow, with just enough space in between for the sow to lie down. When sows were confined in the SWAP pens they had more space in both width and length than in a traditional crate, but they could not turn around. In addition, the sloped wall was part of the confinement to support sows when lying down. Thus, differences between studies where sows have been confined in crates and the results obtained in study III might be explained by the different types of confinement. However, as this is the first research on this type of confinement, the effects of confinement can only be related to other systems where sows are physically restricted, such as crates.

CONCLUSION

The results obtained in this thesis have provided new knowledge on piglet mortality in loose housed lactating sows as well as insight into the concept of temporary confinement, particularly in relation to piglet mortality and sow behaviour and physiology.

Housing of sows in designed farrowing pens during farrowing and lactation was associated with increased piglet mortality compared to traditional farrowing crates and farrowing pens were not a robust type of system. Confinement from two days before farrowing did not seem to influence the progress of farrowing, but early piglet mortality was higher in loose housed sows compared to sows that were confined for four days after farrowing.

Introducing the concept of temporary confinement in designed farrowing pens showed that confinement of loose housed sows for four days after farrowing could reduce piglet mortality from litter equalisation to day 4, but not to a level that affected total piglet mortality. Confining sows from two days before expected farrowing to day 4 after farrowing reduced piglet mortality before litter equalisation as well as to day 4 and, consequently, total piglet mortality was reduced. The period from birth to litter equalisation was highlighted as an important period for piglet survival and it seemed that confinement during this period was necessary to reduce total piglet mortality. Sow behaviour was generally characterized by prolonged lateral lying and few postural changes. Confinement to day 4 reduced the frequency of lying down and rolling however these effects were mainly seen on day 2 and 3 after farrowing. Confinement also influenced nursing behaviour and more so if sows were confined before farrowing than if confinement was imposed after farrowing. The physical restriction imposed on the confined sows did affect behaviour but as effects were mainly evident on day 3, confinement for a few days seemed to influence sow behaviour to a minor extent. The behavioural effects of confinement was not reflected in saliva cortisol concentrations but confinement before farrowing decreased saliva cortisol concentrations and the results indicated that the effects of confinement before farrowing had more influence on saliva cortisol concentrations after farrowing than the confinement per se.

The idea of temporary confinement as a means to achieve low piglet mortality and at the same time impose as little detriment to the sows as possible was supported by the findings in this thesis and further improvement of strategies for temporary confinement could potentially ensure high level of sow and piglet welfare in designed farrowing pens.

PERSPECTIVES

Implementing loose housed system for farrowing and lactating sows in commercial pig production is mainly challenged by the risk of increased piglet mortality. In this thesis it was shown that temporary confinement could reduce piglet mortality and providing an option of confinement may thus ease the transition from confined to loose housed systems. It provides an alternative that can decrease the risks associated with loose housed sows and is therefore likely more commercially viable than a completely loose housed system. Although sows did not have freedom of movement at all times, using a strategy of temporary confinement is expected to improve sow welfare substantially. In traditional farrowing crates in Denmark sows are confined for 5-7 days before farrowing and 21-28 days after farrowing, whereas the strategies for temporary confinement used in this thesis left sows in confinement 2-3 days before farrowing and 4 days after farrowing. Implementation of temporary confinement in commercial production will thus ensure that sows are loose housed for the majority of the time they are in the farrowing unit.

However, this thesis also showed that there remain a number of questions to be answered. Sows were confined from day 114 if they were confined before farrowing and confinement was removed on day 4 after farrowing. Nest building behaviour was not included in this thesis but it was indicated that sow physiology was affected by confinement before farrowing. As confinement has been shown to have negative effects on nest building behaviour (e.g. Jarvis et al., 1997; Jarvis et al., 2004) the consequences of confining before farrowing should be studied further. As there are no piglets present during nest building, there is no reason per se to confine the sows. However, the results in this thesis suggested that sows should be confined before farrowing in order to reduce piglet mortality. Further studies should look into the time of confinement to see if sows should be confined closer to farrowing or even after the birth of the first piglet. Similarly, the number of days in confinement after farrowing should be studied further. It was suggested that sow behaviour was somewhat affected on day 2 and 3 after farrowing, indicating that a shorter period of confinement may be preferable in relation to sow welfare. In addition, it cannot be determined from the results in this thesis, if a reduction in piglet mortality could be achieved by confining sows for a shorter period of time. It is therefore relevant to look further into the strategies of confinement to see if the influence on sows can be further diminished but at the same time maintain a reduction in piglet mortality. The results also indicated that there was a risk of higher piglet mortality when the sows were no longer confined and there were indications of a different nursing pattern when sows were confined. Further studies should therefore not only be focused on the time the sows are in confinement, but also try to establish how the removal of the confinement affects the sows and the piglets. This is furthermore important for the development of management strategies in temporary confined systems.

This thesis showed that a number of sows could perform well in loose housed systems, but also that a number of sows did not. Thus, identifying sows that ought to be confined in order to achieve satisfactory results is highly relevant. The importance of parity and litter size in relation to piglet mortality was established by the results obtained in this thesis. If crushing or poor maternal abilities are consistent over parities (Jarvis et al., 2005), valuable information about expected performance can potentially be gathered from the first few parities. In addition, there may be other indicators that can be used to identify sows with risk of high piglet mortality, e.g behavioural differences (Valros et al., 2003; Johnson et al., 2007). Maternal behaviour has been identified as one of the key factors when it comes to achieving good results in loose housed systems (Arey, 1997). Understanding why sows are not able to perform and identifying ways to detect poor mothers before crushing occurs can improve management strategies and help direct attention to sows with risk of high mortality.

The management needed to make loose housed systems succeed is not necessarily the same as that in crated systems. For most farmers, implementing loose housing for farrowing and lactating sows will require a period of adaptation until they have acquired an understanding of the systems and the management procedures working in it. In such a learning process, an option of confinement can help minimize the consequences of insufficient management routines. In addition, as the management procedures around loose housing develops, the need for confinement will likely be restricted to a short period of time and at some point, there may not be a need for confinement anymore. Nonetheless, development of managements protocols for housing of loose lactating or temporary confined loose lactating sows are required.

Finally, the economical perspective should be considered. Both capital and running cost are expected to be higher in a temporary confined system, and for now there is no indication that a premium can be achieved for the product. For the system to be commercially viable the coherence between production cost and the revenue should improve. Due to the novelty of the system, temporary confinement in designed farrowing pens has not yet been proven to be a stable and robust system. However, with improvements and further development of strategies for temporary confinement, this system does seem to provide a basis for implementation of loose housed farrowing and lactating sows in commercial herds.

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INCLUDED PAPERS

Paper I

Higher preweaning mortality in free farrowing pens compared with farrowing crates in three commercial pig farms

Hales J., V.A. Moustsen, M.B.F. Nielsen and C.F. Hansen.

Published in Animal

Animal (2014), **8:1**, pp 113–120 © The Animal Consortium 2013
doi:10.1017/S1751731113001869

animal

Higher preweaning mortality in free farrowing pens compared with farrowing crates in three commercial pig farms

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(Received 10 April 2013; Accepted 18 August 2013; First published online 24 October 2013)

If loose-housed farrowing systems are to be an alternative to traditional farrowing crates, it is important that they can deliver the same production results as can be achieved in farrowing crates under commercial conditions. The aim of this study was to compare preweaning mortality in farrowing crates and free farrowing pens (FF-pens) within herds that had both systems. The study was conducted over 2 years in three commercial Danish herds that had FF-pens as well as traditional farrowing crates in their farrowing unit. Piglet mortality was analysed in two periods: before litter equalisation and after litter equalisation. Linear models were used to analyse effects of housing (crate or pen), herd (Herd A, B or C), parity (parities 1, 2, 3 to 4 or 5 to 8) as well as the effect of number of total born piglets on mortality before litter equalisation, and the effect of equalised litter size on piglet mortality after litter equalisation. All corresponding interactions were included in the models. Before litter equalisation piglet mortality was higher ($P < 0.001$) in pens (13.7%) than in crates (11.8%). Similarly, piglet mortality after litter equalisation was higher in pens than in crates in all three herds, but the difference between pens and crates were dissimilar ($P < 0.05$) in the different herds. In addition, piglet mortality, both before ($P < 0.001$) and after litter equalisation ($P < 0.001$), grew with increasing parity of the sows. Mortality before litter equalisation moreover increased with increasing number of total born piglets per litter ($P < 0.001$), and mortality after equalisation increased when equalised litter size increased ($P < 0.001$). No significant interactions were detected between housing and parity or housing and litter size for any of the analysed variables. In conclusion, there is knowledge how to design pens for free farrowing; but this study showed a higher preweaning mortality in the FF-pen. Nonetheless a noteworthy proportion of the sows in the FF-pens delivered results comparable to those farrowing in crates. This indicates that FF-pens are not yet a robust type of housing for farrowing sows.

Keywords: animal welfare, farrowing accommodation, loose sows, piglet mortality

Implications

In most pig producing countries, lactating sows are placed in farrowing crates to avoid crushing of the suckling piglets by the sow, even though crates place behavioural restrictions on the sow. The current study showed that housing sows in free farrowing pens (FF-pen) led to increased piglet mortality compared with crates. Therefore, additional research is needed before the FF-pen can be implemented without increasing piglet mortality.

Introduction

The majority of sows are confined in crates during farrowing and lactation. From an economic perspective, there are several advantages of this type of farrowing accommodation as crates are space- and labour-saving, facilitate high levels of hygiene in the pen, and are designed to ensure piglet survival. However, restricting sows in farrowing crates has been shown to influence the behaviour and physiology of the sow negatively (Jarvis *et al.*, 2006; Baxter *et al.*, 2012). With a growing societal concern for animal welfare, there is an increasing interest in abolishing farrowing crates. Nevertheless, uptake of non-crated farrowing systems by pig producers has been limited, mainly due to fear of increased piglet mortality. This concern has been addressed in several studies, but so far with equivocal results. For example, Cronin *et al.* (2000), Weber *et al.* (2007) and KilBride *et al.* (2012) suggested that piglet mortality did not differ between pens and crates, whereas for instance Blackshaw *et al.* (1994), Weary *et al.* (1998) and Marchant *et al.* (2000) showed greater piglet mortality in pens compared with crates.

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There is a public interest in abolishing the farrowing crate, but, for instance, the European Food Safety Authority has expressed caution when it comes to implementing farrowing pens because of the risk of higher levels of piglet mortality (European Food Safety Authority, 2007). Piglet mortality is affected by numerous factors like pen design, genetics, management and litter size (Weary *et al.*, 1998; Andersen *et al.*, 2007). Currently, the average litter size in Denmark is 16.6 total born piglets per litter (Vinther, 2012), which is considerably higher than reported in previous studies comparing piglet mortality in pens and crates. A free farrowing pen (FF-pen) needs to function for sows with large litters, and consequently an FF-pen was developed in a joint research project between several parties of the pig industry, the Danish Animal Welfare Society, and Aarhus University (Anonymous, 2011; Baxter *et al.*, 2012). The FF-pen was designed to fit the modern day sow and to fulfil the sow's requirement for space and freedom to move around (Moustsen *et al.*, 2011). At the same time, the FF-pen was designed with consideration to the piglets' needs for heat and protection against dangerous situations. The objective of this study was to compare levels of preweaning piglet mortality in traditional farrowing crates and FF-pens in commercial production herds with both types of systems. The hypothesis tested was that preweaning mortality did not differ between farrowing crates and FF-pens.

Material and methods

The study was conducted in accordance with the guidelines of the Danish Ministry of Justice with respect to animal experimentation and care of animals under study. The piggeries in this study were selected because they had chosen the FF-pen as part of their farrowing unit and had been using the pens for at least a year when the data collection started. From 2010 to 2012, data were collected in three commercial Danish piggeries (Herd A, B and C) with 400, 580 and 640 sows, respectively. All herds had more traditional farrowing crates than FF-pens, so consequently only a subset of the farrowing crates was used for data collection.

Housing

In all three herds, sows were housed in individual stalls for 4 weeks in the mating unit. During gestation, the sows were housed in groups with floor feeding in Herd A and in individual stalls in Herds B and C. One week before expected parturition, the sows were moved to the farrowing unit and randomly allocated to either farrowing crates or pens. The layout of the farrowing pens was similar in the three herds (Figure 1), apart from a few minor details. The floor consisted of two-thirds solid or drained floor (<10% void) and one-third fully slatted (>40% void) cast iron flooring. The creep area for piglets was placed adjacent to the aisle to allow easy access to piglets for inspection and handling. The creep area had floor heating and a 150 W heat lamp installed in the cover. The creep entrance as well as the cover of the creep

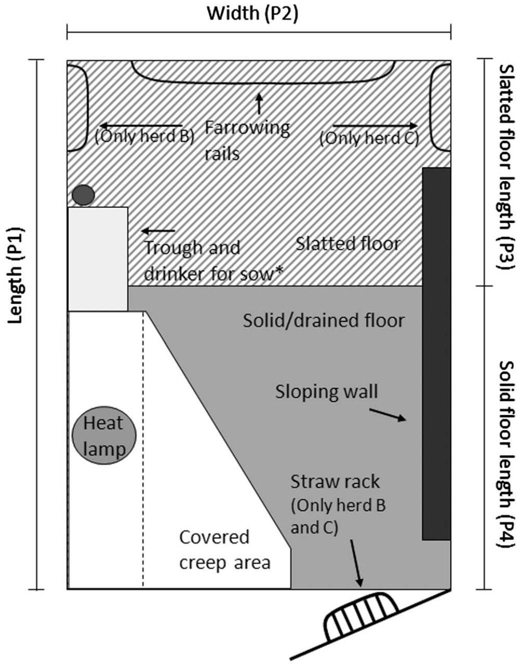

Figure 1 Layout of free farrowing pen (FF-pen) in Herds A, B and C. Dimensions: Herd A: P1 = 270 cm, P2 = 198 cm, P3 = 120 cm, P4 = 150 cm; Herd B: P1 = 280 cm, P2 = 185 cm, P3 = 160 cm, P4 = 120 cm; Herd C: P1 = 300 cm, P2 = 210 cm, P3 = 118 cm, P4 = 182 cm. *In Herd A, the trough was placed in the corner between P1 and P2.

was adjustable. The front of the creep was fitted with six fingers to prevent the sow from closing the piglets inside the creep in situations where the sow laid down in front of the creep entrance. On the wall between the creep and the back wall there was a trough and a drinker for sows and piglets. The pen wall opposite the creep was fitted with a sloping wall to support the sow when lying down and to protect the piglets from crushing (Damm *et al.*, 2005; Damm *et al.*, 2006). The sloping wall was placed 20 cm above the floor and at the bottom it was 20 cm away from the pen wall so that piglets were able to pass behind and escape underneath. The back wall of the pen was fitted with a farrowing rail 20 cm above the floor as a piglet protection feature. The layout of the pens with farrowing crates was also similar in all three herds (Figure 2). The pens had traditional farrowing crates as well as two-thirds solid floor and one-third fully slatted floor. In the adjustable cover of the creep, a 150 W heat lamp was fitted. A separate drinker for piglets was located at the slatted floor.

In Herd A, there were 54 traditional farrowing crates and 39 individual farrowing pens. The FF-pens were constructed in an existing building in the farrowing unit. All sections of the farrowing unit were ventilated with an equal pressure system with a desired temperature of 20°C to 22°C. The FF-pens in Herd A had an area of 5.4 m^2, and the creep

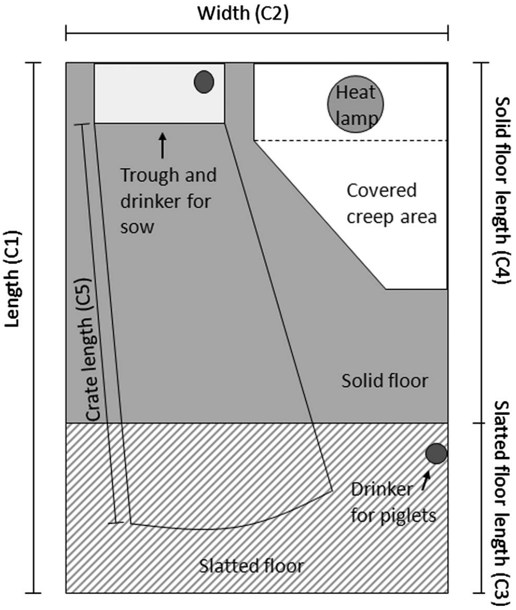

Figure 2 Layout of pen with farrowing crate in Herds A, B and C. Dimensions: Herd A: C1 = 245 cm, C2 = 140 cm, C3 = 95 cm, C4 = 150 cm, C5 = 195 cm; Herd B: C1 = 257 cm, C2 = 156 cm, C3 = 100 cm, C4 = 157 cm, C5 = 190 cm; Herd C: C1 = 260 cm, C2 = 156 cm, C3 = 100 cm, C4 = 160 cm, C5 = 200 cm.

covered an area of 0.86 m^2. The floor in the lying area of the pen was solid and the trough was placed close to the corner at the back wall of the pen. In Herd A, there was no straw rack on the pen gate. In Herd A, the pens with farrowing crates measured 3.4 m^2, of which the creep covered an area of 0.42 m^2. In Herd B, there were 146 traditional crates and 12 individual farrowing pens. The farrowing unit was diffuse ventilated with a preferred temperature of 20°C to 22°C. The FF-pens, which were constructed in an existing building, measured 5.2 m^2, and the creep area was 1.15 m^2. The floor in the lying area was drained (<10% void), and the trough was placed next to the creep. Furthermore, there was an additional farrowing rail between the trough and the back wall and the pen gate was fitted with a straw rack. The pens with farrowing crates in Herd B had an area of 4.0 m^2, and the creep area in the pens with crates was 0.89 m^2. Herd C had 136 traditional farrowing crates and 14 individual farrowing pens. The farrowing units had a desired temperature of 21°C and were diffuse ventilated. The FF-pens measured 6.3 m^2 of which the creep area covered 0.96 m^2. There was solid flooring in the lying area of the pens, and the trough was placed next to the creep. Moreover, there was an additional farrowing rail between the sloping wall and the back wall of the pens, and the pen gate was fitted with a straw rack. The pens with traditional farrowing crates in Herd C had an area of 4.1 m^2 and the creep area in the crates was 0.41 m^2.

Animals and management

Data from 1416 Danish Landrace × Danish Yorkshire sows and their litters were collected. All sows had been artificially inseminated with semen from Duroc boars (Hatting KS, Horsens, Denmark). All management routines were conducted in accordance with the normal practices of the herds, and there was no difference in the handling of the sows and litters placed in crates and of those housed in pens. The pens were placed in existing buildings, so number of pens did not necessarily equal batch size and/or reproduction cycle of the sows. Therefore, the sows did not farrow in the same system at consecutive farrowings. Within herds, sows placed in crates and pens were fed the same diets formulated to fulfil the requirements for this genotype of animals. In all diets, barley, wheat and soya bean meal were the main ingredients, but compositions differed between herds. Herds A and C used a dry feed system, whereas Herd B used a liquid feeding system. The sows were fed two times a day, and both sows and piglets had *ad libitum* access to water via drinking nipples.

Litters were equalized by cross-fostering piglets born within the same 12 to 24 h when it was expected that all piglets had consumed colostrum. First-parity sows were equalised to 14 piglets per litter, whereas older sows were entrusted 13 piglets per litter unless the sows had fewer functional teats. If there were surplus piglets after litter equalisation, these were fostered to nurse sows that were not part of this study. Piglets deemed weak and unable to survive throughout lactation if ignored were fostered to nurse sows. Traumatized, diseased or piglets that for other reasons were believed unable to survive to weaning were euthanized by blunt-force trauma. All piglets had iron injections, were tail docked, and males were surgically castrated on days 3 or 4 after farrowing.

Records

Within herd, data were collected from sows farrowing in both crates and pens. As the study focused on the potential for pens, a higher number of sows farrowing in pens than in crates was included.

When the sow was placed in the farrowing unit, the date and parity were recorded. Farrowing date was logged when the onset of farrowing was observed, and the number of stillborn and live-born piglets was noted when the farrowing was finished after expulsion of the placenta. Obstetric aid was performed when deemed necessary and was noted on the sow card. The date of litter equalisation was recorded together with the number of piglets that were taken away from or added to a sow. Dead piglets were not subjected to *postmortem* examination, but were recorded with a date and a cause of death judged by the staff. All piglets that were found dead when termination of farrowing was recorded were enumerated as stillborn.

Calculations and statistical analysis

All statistical analyses were performed using SAS ver. 9.3 (SAS Institute Inc., Cary, NC, USA) with each litter or sow as the experimental unit and statistical significance accepted at $P < 0.05$. Piglet mortality was analysed in two periods: before and after litter equalisation. Litter size differed in these periods, and this changed the basis for calculating percentages of dead piglets. The effect of housing on total born (stillborn + live-born piglets), live-born and equalised litter size was analysed univariately by the GLM procedure of SAS, with housing (pen or crate), herd (Herd A, Herd B or Herd C), parity of the sow (parity 1, parity 2, parities 3 to 4 or parities 5 to 8), and the corresponding interaction terms included in the model.

Data on stillborn piglets, number of live-born piglets that died before litter equalisation, and mortality before and after litter equalisation were discrete. A GLM with an underlying Poisson distribution was fitted to these traits using the GENMOD procedure, which is a transformation of data to a linear regression with a logarithmic function. Housing, herd, parity and the corresponding interaction terms were included in the model. For stillborn, live-born deaths and piglet mortality before litter equalisation, litter size (total born) was included as a covariate. Piglet mortality after litter equalisation was analysed with the same model, but with equalised litter size as a covariate. If an interaction term was not significant ($P > 0.05$), it was removed from the model. Estimated least-squares means are presented for the normally distributed data. For the Poisson distributed data, the back-transformed values are presented.

Sows were divided into two groups (low and high mortality) based on their piglet mortality both before and after litter equalisation. The purpose was to analyse the proportions of sows that performed well in the pens. The threshold for low mortality was set according to the median value for the sows housed in crates. Before litter equalisation, sows were grouped as low mortality before equalisation (piglet mortality ⩽ 11%) or high mortality before equalisation (piglet mortality > 11%). After litter equalisation, sows were divided into low mortality after equalisation (piglet mortality ⩽ 7%) and high mortality after equalisation (piglet mortality > 7%). Differences in the proportions of low and high mortality sows were analysed by use of χ^2 analyses.

Results

During the 2-year period, information regarding 1416 farrowings in the three herds was collected. Of these farrowings, 48 litters were removed from the statistical analyses because of insufficient quality of the data. The results therefore represent information from 735 farrowings in loose pens and 633 farrowings in crates. The analysis of sow parity showed an interaction between herd and housing ($P = 0.024$). In Herd C, the sows in pens were younger than the sows in crates (crates: 3.4 ± 0.11, pens: 2.9 ± 0.13, $P = 0.004$), whereas there was no difference in sow parity between pens and crates in Herds A (crates: 3.4 ± 0.23, pens: 3.0 ± 0.12, $P = 0.087$) and B (crates: 3.4 ± 0.12, pens: 3.6 ± 0.12, $P = 0.453$).

Piglet mortality before litter equalisation

Results on piglet mortality before litter equalisation are presented in Table 1 and Figure 3. There was no effect of housing system on the number of total born piglets ($P = 0.772$) or on the number of live-born piglets ($P = 0.529$). The number of stillborn piglets was greater among sows housed in pens compared with crates ($P = 0.041$) in Herd B, whereas housing had no effect on the number of stillborn piglets in Herd A ($P = 0.706$) and Herd C ($P = 0.077$).

The number of live-born piglets that died before litter equalisation was greater ($P < 0.001$) in pens (0.8) than in crates (0.5). Overall piglet mortality before litter equalisation expressed as numbers was also greater ($P < 0.001$) in pens (2.3) compared with crates (2.0). Expressed as percentage, overall piglet mortality before litter equalisation remained higher ($P < 0.001$) in pens (13.7%) than in crates (11.8%). The proportion of sows with high piglet mortality (mortality > 11%) before litter equalisation was greater in

Table 1 *The effect of housing sows in farrowing crates and free farrowing pens in three herds on production results and piglet mortality before litter equalisation*[1]

	Herd A		Herd B		Herd C			*P*-value		
	Crate	Pen	Crate	Pen	Crate	Pen	rmse	Housing	Herd	Housing × Herd
Sows (*n*)	68	275	268	238	297	222				
Total born[2] (*n*)	17.0	17.0	17.3	17.4	16.2	15.9	3.36	0.772	<0.001	0.700
Live-born[2] (*n*)	15.2	15.1	15.6	15.4	14.8	14.7	3.21	0.529	0.002	0.939
Stillborn[3] (*n*)	1.5^{abd}	1.6^{ab}	1.4^{ad}	1.6^{b}	1.4^{cd}	1.2^{c}	–	0.002	0.851	0.028
Live-born dead[3,4] (*n*)	0.5	0.7	0.5	0.9	0.4	0.7	–	<0.001	0.002	0.467
Mortality[3,5] (%)	12.6	14.2	12.1	15.8	10.7	11.7	–	<0.001	<0.001	0.065

[a,b,c,d]Values in a row without a common superscript differ ($P < 0.05$).
[1]Analysed using generalised linear models, with housing, herd, parity of the sow and the corresponding interaction terms included in the model.
[2]Values are least-squares means.
[3]Discrete data analysed using a generalised linear model with an underlying Poisson distribution. Consequently back-transformed values are presented.
[4]Live-born piglets dying before litter equalisation.
[5]Sum of stillborn and live-born piglets dying before litter equalisation.

pens (66%) compared with crates (52%; $P=0.001$) in Herd B. In Herd A (pens: 58%, crates: 47%; $P=0.110$) and Herd C (pens: 45%, crates: 44%; $P=0.773$), the percentage of sows with high piglet mortality was not different between pens and crates.

Piglet mortality after litter equalisation

Results on piglet mortality after litter equalisation are presented in Table 2 and Figure 3. As planned, equalised litter size did not differ between FF-pens and crates ($P=0.218$). Overall piglet mortality after litter equalisation was higher in pens compared with crates in all herds. Nonetheless, there was an interaction between housing and herd ($P=0.019$), as the increase in piglet mortality in the pens compared with the crates was dissimilar in the different herds. In Herd A, mortality in pens was 8.5 percentage points higher than mortality in crates and in Herds B and C the corresponding numbers were 4.4 percentage points and 1.9 percentage points, respectively.

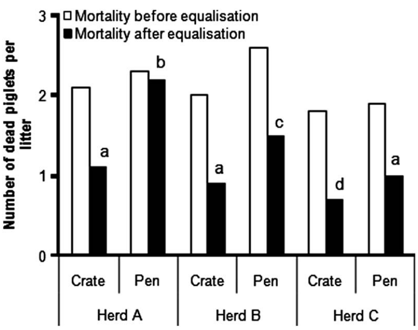

Figure 3 Piglet mortality, expressed as numbers, in crates and pens in Herds A, B and C. White bars = mortality before litter equalisation, black bars = mortality after litter equalisation. *P*-value for herd × housing interactions: mortality before equalisation: $P=0.107$; mortality after equalisation: $P=0.031$. Black bars with different superscripts differ ($P<0.05$).

The 1st week after litter equalisation piglet mortality was greater in pens than in crates in Herd A ($P<0.001$) as well as in Herd B ($P<0.001$) and Herd C ($P=0.013$). Again, the magnitude of the difference in mortality in FF-pens and farrowing crates was greater in Herd A and Herd B compared with the difference in Herd C expressed as an interaction between housing and herd ($P=0.018$). In the 2nd week, after litter equalisation mortality remained greater ($P<0.001$) in pens (1.8%) compared with crates (1.0%), and this was also the case in weeks 3 to 4 with a mortality of 1.2% in pens *v.* 0.8% ($P=0.009$) in crates. The proportion of sows with high piglet mortality after equalisation was greater in pens (77%) than in crates (62%; $P=0.012$) in Herd A. The same pattern was found in Herd B where 74% of sows in pens had high piglet mortality and 51% of sows in crates had high piglet mortality ($P<0.001$). In Herd C, there was no difference in the proportion of sows with high mortality in pens (52%) and crates (46%; $P=0.175$).

Parity and litter size

No significant interactions were detected between housing and parity or housing and litter size for any of the analysed variables. As expected, the number of total born piglets increased with sow parity ($P<0.001$) as did the number of live-born piglets ($P<0.001$) (Table 3). The number of stillborn piglets increased with increasing parity of the sows in all herds, but an interaction between herd and parity ($P=0.013$) showed that this increase was dissimilar between herds. Moreover, the number of stillborn piglets increased with increasing number of total born piglets ($P<0.001$). With increasing parity of the sow, there was an increased number of live-born deaths as well as an increase in overall mortality before and after equalisation (Table 3). A higher number of total born piglets also increased the number of live-born deaths ($P<0.001$) as well as overall mortality before equalisation ($P<0.001$). The equalised litter size decreased with increasing parity but with different patterns in the three herds ($P=0.023$). When equalised litter size

Table 2 *The effect of housing sows in farrowing crates and free farrowing pens in three herds on production results and piglet mortality after litter equalisation*[1]

	Herd A		Herd B		Herd C			*P*-value		
	Crate	Pen	Crate	Pen	Crate	Pen	rmse	Housing	Herd	Housing × Herd
Sows (*n*)	68	275	268	238	297	222				
Equalised litter size[2] (*n*)	13.3	13.5	13.8	13.8	13.0	12.9	0.97	0.218	<0.001	0.139
Mortality[3,4] (%)	8.2^{a}	16.7^{b}	7.0^{a}	11.4^{c}	5.2^{d}	7.1^{a}	–	<0.001	<0.001	0.019
Mortality week 1[3,4] (%)	5.4^{ad}	11.3^{b}	4.4^{ad}	7.7^{c}	4.0^{a}	5.3^{d}	–	<0.001	<0.001	0.018
Mortality week 2[3,4] (%)	0.9	2.8	1.6	2.3	0.6	1.0	–	<0.001	<0.001	0.143
Mortality week 3 to 4[3,4] (%)	1.5	2.2	1.0	1.2	0.3	0.6	–	0.009	<0.001	0.400

[a,b,c,d] Values in a row without a common superscript differ ($P<0.05$).
[1] Analysed using GLM, with housing, herd, parity of the sow and the corresponding interaction terms included in the model.
[2] Values are least-squares means.
[3] Discrete data analysed using a generalised linear model with an underlying Poisson distribution. Consequently back-transformed values are presented.
[4] Piglet mortality after litter equalisation.

Table 3 *Effects of sow parity on number of total and live-born piglets, live-born dead and overall piglet mortality before and after litter equalisation*[1]

	Parity					
	1	2	3 to 4	5 to 8	rmse	*P*-value
Sows (*n*)	299	285	416	368		
Total born[2] (*n*)	14.7[a]	16.9[b]	18.2[c]	17.5[d]	3.36	<0.001
Live-born[2] (*n*)	13.8[a]	15.5[b]	16.2[c]	15.0[b]	3.21	<0.001
Live-born dead[3,4] (*n*)	0.4[a]	0.7[b]	0.6[b]	0.7[b]	–	<0.001
Mortality before litter equalisation[3,5] (%)	9.3[a]	12.1[b]	13.3[c]	17.5[d]	–	<0.001
Mortality after litter equalisation[3] (%)	5.8[a]	7.8[b]	10.7[c]	11.3[c]	–	<0.001

[a,b,c,d]Values in a row without a common superscript differ ($P < 0.05$).
[1]Analysed using GLM, with housing, herd, parity of the sow and the corresponding interaction terms included in the model. Effects of housing and herd illustrated in Tables 1 and 2.
[2]Values are least-squares means.
[3]Discrete data analysed using a generalised linear model with an underlying Poisson distribution. Consequently back-transformed values are presented.
[4]Live-born piglets dying before litter equalisation.
[5]Sum of stillborn and live-born piglets dying before litter equalisation.

increased, there was an increase in piglet mortality after equalisation calculated as numbers ($P < 0.001$).

Piglet mortality in the 1st week was lower among the younger (parities 1 to 2) sows ($P < 0.001$). The effect of parity in the 2nd week differed between herds ($P = 0.001$). In Herd A and Herd B, older sows (parity 3 or more) had a higher piglet mortality than younger sows, but this was not the case in Herd C.

Discussion

Preweaning mortality

Overall piglet mortality was greater in FF-pens than in crates before litter equalisation, and the same was seen after litter equalisation. These results contradict previous studies on preweaning mortality in commercial herds where it has been reported that piglet losses in pens were not greater than in crates (Weber *et al*., 2007; KilBride *et al*., 2012). In our study, the total number of piglets born in a litter was 17.0, 17.4 and 16.0 piglets in herds A, B and C, respectively. This corresponds to the current national Danish average (Vinther, 2012), but is considerably larger than the average litter size of 11.0 piglets in Weber *et al.* (2007) and KilBride *et al.* (2012). Moreover, Weber *et al.* (2007) only included litters with 3 to 19 piglets in their data and only litters where no piglets had been added or removed for fostering. Cross-fostering is a standard procedure in Danish herds with large litters, and disregarding litters that were cross-fostered would not yield representative data. These differences imply that the conditions in the current study were different from the conditions in Weber *et al.* (2007) and KilBride *et al.* (2012), and this could have affected the production and hence results on piglet mortality.

Some of the studies that investigated piglet mortality in pens and succeeded in achieving rates of piglet mortality comparable to those in farrowing crates were conducted in pens that were larger than $5\,m^2$ (Weary *et al*., 1998; Andersen *et al*., 2007; Weber *et al*., 2007). Subsequently, it has been suggested that high levels of piglet losses could be avoided if pens were larger than $5\,m^2$ (Weber *et al*., 2007; Wechsler and Weber, 2007). Levels of mortality in FF-pens were in this study higher than in crates, even though pen size exceeded $5\,m^2$ in all three herds (5.3 to $6.3\,m^2$). To our knowledge, the influence of pen size on piglet mortality has not yet been studied experimentally, but results from this study indicate that not only the size of the pen is of importance when aiming at a reduction in piglet losses. It is reasonable to assume that for the sow to perform certain behaviours, a certain minimum space is required (Baxter *et al*., 2011), but it may be equally important to consider the dimensions of the pen.

The proportion of sows with high mortality after litter equalisation was higher in pens than in crates in Herds A and B and equal in Herd C. Nevertheless, a proportion of the sows in pens had levels of mortality that were similar to the levels of sows in farrowing crates, which suggests that there are sows that perform well in the FF-pen. Previous work has demonstrated that sow behaviour influenced piglet mortality and that certain movements are more risky than others in relation to piglet crushing (Weary *et al*., 1996; Marchant *et al*., 2001; Danholt *et al*., 2011). It is likely that individual differences in sow behaviour and temperament could explain why a large proportion of sows did not perform well in the pens. In a review of lying down and rolling behaviour of sows, Damm *et al.* (2005) suggested that farrowing pens should be designed with supportive surfaces the sow can lean against when lying down. The pens in this study were fitted with a sloping wall, which has been shown to be an attractive form of support when lying down (Damm *et al*., 2006). Nonetheless, a high proportion of the sows had higher levels of mortality, which indicates that the design features of the pen only to a certain extent were able to reduce piglet mortality.

In a recent study of confinement of lactating sows, Moustsen *et al.* (2013) housed the animals in a swing-side system. Moustsen *et al.* (2013) showed that piglet mortality was higher when sows were kept loose throughout the experimental period than when sows were kept in crates after farrowing. However, the pens in the study by Moustsen *et al.* (2013) did not fulfil all design recommendations to meet the biological needs of loose-housed farrowing and lactating sows (Baxter *et al.*, 2011). Our results showed that even though the design of the pen was more satisfactory and actually incorporated more of the recommendations made by Baxter *et al.* (2011) it was still not possible to achieve the same level of mortality as in farrowing crates. In our study, the difference in mortality between pens and crates was greatest in the 1st week after farrowing. The issue is thus to reduce mortality in the early part of lactation, and it may be that confining the sow for a few days after farrowing in this designed pen would render levels of mortality similar to those that can be obtained in farrowing crates.

Influence of parity on piglet mortality

The results in the current study showed that mortality increased with increasing parity both before and after litter equalisation. Previous studies have established a similar unfavourable relationship between increased parity and preweaning survival (Jarvis *et al.*, 2005; Weber *et al.*, 2009; Andersen *et al.*, 2011). In the present study, first-parity sows gave birth to fewer live-born piglets than older sows. Increased litter size has a negative impact on piglet mortality (Andersen *et al.*, 2011) and a greater number of piglets in the pen make more piglets available for crushing when the sow lies down (Weary *et al.*, 1998). However, there were no difference in the number of live-born deaths between sows of parities 2, 3 to 4 and 5 to 8, indicating that not only the number of piglets caused older sows to have a higher piglet mortality. In addition, results from the current study showed that older sows were the ones that were equalised to the smallest litters, and yet mortality after equalisation was higher in older sows. It seems that older sows did not perform as well as younger sows, and this also indicates that maternal and behavioural differences between young and old sows influence piglet mortality. Another thing to consider is that older sows in the FF-pens were likely to have farrowed in crates in their previous parities and did as such not have any experience with the free farrowing system. Previous housing experience can influence sow behaviour during early lactation (Cronin *et al.*, 1996; Weng *et al.*, 2009) and this can also explain why older sows seemed to perform worse than younger sows. Our results also showed that older sows had more stillborn piglets; but this might be linked to the higher number of total born piglets of older sows (Pedersen *et al.*, 2006). However, older sows did not perform worse in pens than in crates in comparison to younger sows in our study.

Influence of litter size on piglet mortality

An increase in the number of total born piglets was in this study shown to increase piglet mortality before litter equalisation independent of housing system. Accordingly, a higher number of total born piglets has been shown to have negative effects on preweaning survival in both pens and crates (Pedersen *et al.*, 2006; Weber *et al.*, 2009). Piglets that are born in larger litters are more likely to have a lighter birth weight (Quiniou *et al.*, 2002; Wolf *et al.*, 2008), and light birth weight is associated with risk factors such as lower viability (Baxter *et al.*, 2008; Hales *et al.*, 2013), increased risk of hypothermia (Herpin *et al.*, 2002) and increased sibling competition at the udder (Andersen *et al.*, 2011). An investigation into indicators of survival in non-crated systems established that piglets that were born in large litters had increased risk of dying the 1st day after farrowing and that surviving piglets had a higher birth weight than dying piglets (Hales *et al.*, 2013). However, increased sibling competition could also influence the mortality of piglets (Andersen *et al.*, 2011), which is in accordance with our results as piglet mortality after litter equalisation increased with increasing equalised litter size. Equalised litter size might also affect piglet survival, as proposed by Weary *et al.* (1998), because more piglets are 'available' for crushing.

Conclusion

This study showed that loose farrowing in the FF-pen is not yet robust under commercial situations as piglet mortality was higher in FF-pens than in crates. However, a proportion of sows in FF-pens had a level of piglet mortality similar to that of the sows in farrowing crates, indicating that the FF-pens have the capability to deliver the same performance as farrowing crates.

Acknowledgements

The project was funded by the Pig Levy Foundation, The Danish Rural Development Program 2007-2013/The European Agricultural Fund for Rural Development and the Department of Large Animal Sciences, University of Copenhagen. The authors thank the owners and staff of the participating piggeries for their collaboration on this project. In addition, they are grateful to Pia Brandt, Jens Martin Strager, Ann Edal and Julie Krogsdahl for their help with collection of data.

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Paper II

Comparable farrowing progress in confined and loose housed hyper-prolific sows

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Published in Livestock Science

Livestock Science 171 (2015) 64–72

Contents lists available at ScienceDirect

Livestock Science

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

Comparable farrowing progress in confined and loose housed hyper-prolific sows

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ARTICLE INFO

Article history:
Received 3 July 2014
Received in revised form
10 November 2014
Accepted 18 November 2014

Keywords:
Birth duration
Birth interval
Farrowing accommodation
Farrowing duration
Loose sows
Piglet mortality

ABSTRACT

The aim of this study was to determine the effect of confinement from day 114 of gestation and the first four lactation days on farrowing progress and piglet survival. All sows (parity 1–7) were randomly allocated to one of the four treatment groups: confined–confined (CC, $n=30$), confined–loose (CL, $n=32$), loose–confined (LC, $n=28$) or loose–loose (LL, $n=30$). Before and during farrowing sows in CC and CL were confined in crates whereas sows in LC and LL were loose housed in this period. The first four days after farrowing sows in CC and LC were confined in crates whereas sows in CL and LL were loose housed during this time. All sows were loose housed from day 4 until weaning. Compared to loose sows (LC and LL), confinement before and during farrowing (CC and CL) did not affect total born piglets ($P=0.69$), stillborn piglets ($P=0.68$), farrowing duration ($P=0.26$) or birth interval ($P=0.25$). However, birth duration for stillborn piglets tended ($P=0.06$) to be shorter in the loose housed sows than in confined sows. Loose housed sows with short farrowing duration (<5 h) tended ($P=0.06$) to have fewer stillborns than confined sows with short farrowing duration. However, number of stillborn piglets increased with increasing farrowing duration for loose housed sows ($P<0.05$) but not for the confined sows. Loose housed sows also had more live born deaths before litter equalization when farrowing duration increased ($P<0.05$), an effect that was not seen in the confined sows. Piglet mortality was greater for LL sows than for CC, CL and LC sows before litter equalization. After litter equalization and until day 4, piglet mortality varied between treatments ($P<0.001$), with piglet mortality in LC (3.2%) being lower than in CL (9.0%) and in LL (7.5%). Similarly piglet mortality was lower in the CC-treatment (5.0%) than in the CL-treatment (9.0%). From day 4–7 after farrowing sows in CC tended ($P=0.10$) to have greater piglet mortality than sows in LL. In conclusion, confinement from day 114 of gestation until birth of last piglet did not affect farrowing progress compared to sows that were loose housed. However, the results suggested that confinement of sows for four days after farrowing reduced piglet mortality compared to loose housed sows.

1. Introduction

Confinement of sows in farrowing crates limits the performance of a range of behaviors and compromises the welfare of the sows. Studies have shown that restriction of nest building behavior increases physiological stress prior to farrowing (Jarvis et al., 2004, 2001). Farrowing is a major physiological event that involves a series of endocrine changes that could be influenced by an increased level of stress. Thus, increased stress caused by confinement during nest building could affect the progress of farrowing. Oliviero et al. (2008) studied sows in a commercial setting and found longer duration of farrowing

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http://dx.doi.org/10.1016/j.livsci.2014.11.009
1871-1413/

for sows in crates compared to sows in pens. However, this effect could be influenced by nest building material as only sows in pens had access to straw. Moreover, results by Oliviero et al. (2008) are inconsistent with Jarvis et al. (2004), who studied gilts in an experimental setting. Jarvis et al. (2004) did not detect any effect of environment during nest building on duration of farrowing but found that provision of straw extended duration of farrowing. Studies of birth interval in first parity sows have also not shown any differences between crated and penned sows (Jarvis et al., 2004; Pedersen et al., 2011). However, environment may not affect young and older sows in the same way with respect to progress of farrowing (Pedersen and Jensen, 2008) as for instance younger sows generally farrow fewer piglets. Further studies are therefore needed to investigate if and how confinement affects progress of farrowing in commercial conditions with sows of different parities. Nest building is a very active phase pre-farrowing (Wischner et al., 2009) and the effects of behavioral restriction become evident during this period as well as influencing maternal behavior and the physiological status of the sows during lactation (Cronin et al., 1991; Jarvis et al., 2006; Weary et al., 1996a).

The main argument for housing sows in crates is that piglet survival is improved compared to loose housed systems, although studies show contradictory results. Some studies have not found differences in survival between pens and crates (Cronin et al., 2000; Pedersen et al., 2011; Weber et al., 2007), whereas other studies found higher preweaning mortality in pens (Blackshaw et al., 1994; Hales et al., 2014; Marchant et al., 2000). A recent study by Hales et al. (2014) on hyper-prolific sows showed that even though some herds achieved low pre-weaning mortality in pens, mortality rates were not as low as what was achieved in crates. As the majority of dead piglets die within the first week of life (Marchant et al., 2000) the need for confinement in order to reduce piglet mortality may be limited to a few days. Little research has been done on systems with temporary crating where sows are confined for a few days after farrowing. Nonetheless Moustsen et al. (2013) showed that confinement of sows for four days after farrowing was sufficient to reduce piglet mortality to a level that was comparable to sows that were confined from placement in the farrowing unit to 10 days after farrowing.

In traditional farrowing crates it is only possible to keep the sows confined, but until piglets are born there is no need to restrain sows. Recently housing systems are being developed where temporary crating of the farrowing and lactating sows is a possibility. However, no information is available on the impact of confinement for a short period prior to farrowing on farrowing progress.

The aim of the present study was therefore to determine the effect of confinement from day 114 of gestation and the first four lactation days on farrowing progress and piglet survival in a commercial setting. The primary hypothesis was that confinement from day 114 of gestation would prolong duration of farrowing, birth intervals and birth duration. Moreover we hypothesized that confinement would increase stillbirth, and that confinement of the sow during the first four days after farrowing would increase piglet survival compared to loose housed sows.

2. Material and methods

This experiment was conducted in accordance with the guidelines of the Danish Ministry of Justice Act no. 382 (June 10, 1987) and Acts 333 (May 19, 1990), 726 (September 9, 1993) and 1016 (December 12, 2001) with respect to animal experimentation and care of animals under study. The study was conducted in a commercial Danish piggery, which was also used for educational purposes (Graasten Landbrugsskole, Graasten, Denmark), with 400 Danish Landrace x Danish Yorkshire sows.

2.1. Housing and experimental design

Sows were loose housed in a deep-bedded system with individual feeding stalls for four weeks during and after mating. During gestation the sows were group housed and fed individually in electronic feeding stations. The resting areas in the gestation unit were equipped with straw racks that ensured permanent access to straw and the sows had permanent access to water as well. One week before expected parturition day the sows were moved from the gestation unit to individual pens in the farrowing unit. The farrowing unit consisted of three identical sections with 36 individual farrowing pens in each section. The farrowing pens were 5.25 m^2 and were designed with partly solid floor and a swing-side crate, which could be closed for a period of time (Fig. 1). There was a trough with a water nipple that allowed free access to water and a straw dispenser was mounted at the swing-side near the trough. Next to the trough, adjacent to the aisle, there was a

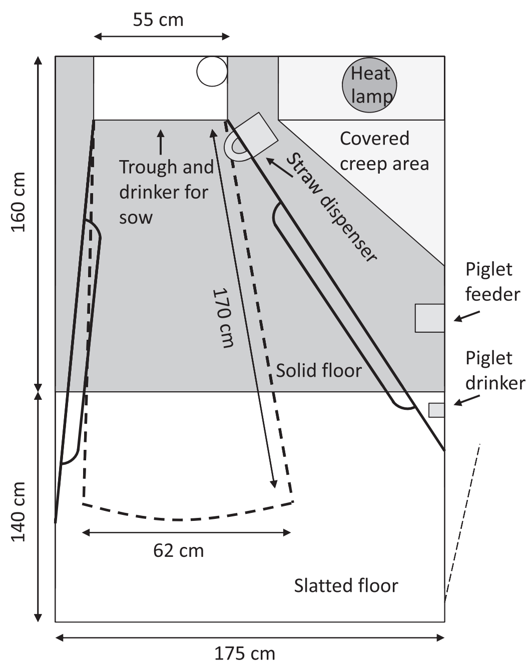

Fig. 1. Illustration of pen design and dimensions for confined and loose housed sows. Solid lines represents housing of loose housed sows and the dashed lines represents housing of confined sows.

covered creep area with a heat lamp installed in the cover and sawdust as bedding. Outside the creep area there was a separate feeder and water nipple for the piglets.

All sows were randomly allocated to one of the four treatment groups: confined–confined (CC), confined–loose (CL), loose–confined (LC) or loose–loose (LL) (Fig. 2). Six batches of 20 sows (five per treatment) were used in this experiment. Until day 113 of pregnancy all animals were loose housed in the individual farrowing pens. In the first observational period from day 114 until the end of farrowing (birth of the last piglet) CC and CL sows were confined in the swing-side crate and were therefore regarded as the same treatment (confined) in this period. Oppositely, LL and LC sows continued to be loose housed from day 114 until the end of farrowing and thus considered as the same treatment (loose) during this period. After farrowing, sows in CC and LC were confined in crates for the first four days after farrowing, whereas sows in CL and LL were loose housed in this period. From day 4 after farrowing and until the experiment ceased on day 7 all sows were loose. The four observational periods in the experiment are illustrated in Fig. 2.

2.2. Animals and management

A total of 120 healthy sows of parity 1 to 7 that were artificially inseminated with semen from Duroc boars (Hatting KS, Horsens, Denmark) were included in this study. During gestation the sows were fed according to body condition using a commercially formulated gestation diet containing 7.85 MJ potential physiological energy/kg (Boisen, 2001), 11.6% crude protein and with barley, wheat and soybean meal as the main ingredients. In the farrowing unit the sows were fed a lactation diet formulated to comply with the requirements of animals with this genotype. The diet was based on barley, wheat and soybean meal with an energy content of 8.16 MJ potential physiological energy/kg (Boisen, 2001) and a crude protein content of 13.5%. Sows were fed twice daily, at 0630 h and 1430 h, and had ad libitum access to water. The sows had permanent access to a straw dispenser containing chopped straw and, in addition, long stemmed wheat straw was supplied daily at 0930 h. All sows received 100–150 g wheat straw from the day they were placed in the farrowing unit until one day before expected farrowing. From the day before expected farrowing and until birth of first piglet the sows received 400–450 g wheat straw daily. If there was any dirty or wet straw in the pen it was cleaned out before the new straw was provided.

Management routines and handling of sows and piglets were conducted in accordance with normal practices of the herd. During the days of farrowing staff conducted regular rounds through the farrowing unit to inspect sows that farrowed. Rounds were conducted approximately every 60 min from 0700 to 1700. All piglets were closed inside the creep at the first feeding of the sows after farrowing. After this first feeding piglets were split-suckled to ensure colostrum for all new-born piglets. Split-suckling was done by letting the 11 smallest piglets nurse while the rest of the litter was closed inside the creep for 2 h. Within 24 h after farrowing litters at primiparous sows were equalized to 14 piglets while litters at multiparous sows were equalized to 13 piglets. Piglets were cross-fostered within each treatment by removing the biggest piglets from litters with surplus and transferring those to litters with a deficit. Additional surplus piglets were fostered to nurse sows outside the experiment.

All piglets were tail docked and received an iron injection at day two after farrowing, and male piglets were injected with pain relieve and surgically castrated at day three. If piglets were traumatized, sick or for other reasons unable to survive to weaning they were humanely euthanized by blunt force trauma.

2.3. Records

Date and time of first observation of start and end of farrowing as well as the number of live born and stillborn piglets were recorded. If the sow received obstetric aid during farrowing it was noted. When litters were equalized the date and time of equalization as well as the number of piglets the litter was equalized to, was logged. Moreover, date and time of finding of any dead piglets was recorded and dead piglets were given a temporary cause of death. Cause of death was subsequently verified or corrected from observation of video recordings and post mortem examinations.

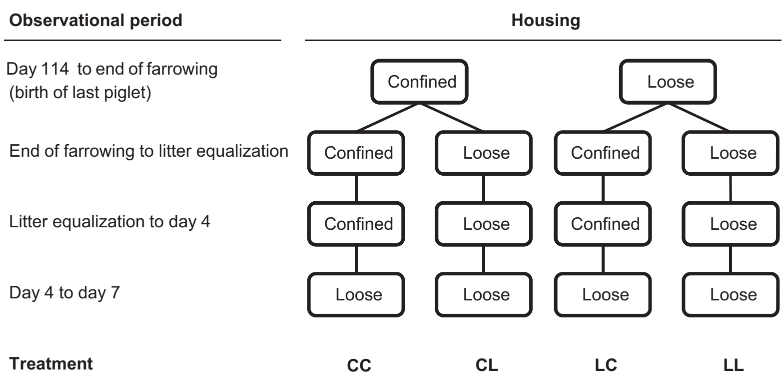

Fig. 2. Illustration of the experimental design that included four observational periods and four treatment groups: confined–confined (CC), confined–loose (CL), loose–confined (LC) and loose–loose (LL).

2.4. Post mortem examinations

All dead piglets were stored at −18 °C until they were subjected to a post mortem examination to ascertain cause of death. Dead piglets were classified as 'stillborn' (lungs not inflated), 'crushed' (obvious signs of trauma or edema), 'euthanized' (blunt force trauma to the head) or 'other' (disease, no signs of crushing or could not be accurately classified at the post mortem examination).

2.5. Video recordings

Video cameras (PTZ security IR-Dome model no. 795JH, PTZ Security, Esbjerg, Denmark) were placed above the sows in the farrowing unit and commenced recording on day 114 of gestation until day 4 after farrowing. The recordings were stored in a binary format that was subsequently converted to common video format by PlayerAP, a part of VisionEye 3.3.14 (PTZ Security, Esbjerg, Denmark). Registration of events was done in Avidemux 2.5.6 (Free Software Foundation Inc., Boston, USA). An observer recorded exact date and time of expulsion of each piglet in a litter as well as whether the piglet was stillborn (no visible movement) or live born.

2.6. Calculation and statistical analysis

All statistical analysis was performed using SAS ver. 9.3 (SAS Institute Inc., Cary, NC, USA) with each litter or sow as the experimental unit. Farrowing duration was calculated as time from birth of first piglet to birth of last piglet and as time from birth of first piglet to birth of last live born piglet. Birth interval was calculated as the time between two succeeding piglets. As an indicator of how long the birth process was for the individual piglet 'birth duration' was calculated as the time from birth of the first piglet to birth of nth piglet meaning that e.g. for the 11th piglet in the birth order birth duration was the time from birth of the first piglet to its own birth. This figure served as an indicator of how long the birth process was for each piglet in a litter. Farrowing duration, birth interval and birth duration exhibited a skewed distribution and were therefore square root transformed before analyzed using the MIXED procedure in SAS. The models included treatment before and during farrowing (confined or loose), parity (parities 1–2 or parity 3 and older), total born piglets per litter (7–18 or 19–28) and the corresponding interaction terms. Analyses of birth interval and birth duration moreover included sow as a random effect and a binary variable, 'still', stating if a piglet was alive at birth or not (live born or stillborn).

Sow parity, number of total born (stillborn + live born), number of live born, and equalized litter size was assumed normally distributed and analyzed using the MIXED procedure of SAS with treatment (CC, CL, LC or LL) as fixed effect. Analysis of total born included parity as fixed effect, and analyses of live born and equalized litter size included both parity and total born as fixed effects. All corresponding interaction terms were moreover included in the models.

Data on stillborn piglets, live born mortality before litter equalization (number of live born piglets that died before equalization/number of live born piglets), live born mortality from litter equalization to day 4 (number of live born piglets that died after equalization/equalized litter size), and mortality from day 4 to 7 (number of dead piglets in period 4/equalized litter size) were discrete. A generalized linear model with an underlying Poisson distribution was fitted to these traits using the GENMOD procedure which is a transformation of data to a linear regression with a logarithmic function. The fixed effects treatment and parity, as well as the corresponding interaction terms, were included in the model. For the analysis of stillborn piglets the number of total born piglets per litter was included as fixed effect. In addition, the effect of farrowing duration (< 5 h, 5–9 h or > 9 h) on stillborn piglets and live born mortality before equalization were analyzed. As the data was discrete it was analyzed using the GENMOD procedure with an underlying poisson distribution. These models included treatment, parity and total born as fixed effects, and the corresponding interaction terms. The risk of dying from crushing was analyzed using the LOGISTIC procedure with the binomial response crushed/not crushed. Treatment and time of death (before or after litter equalization) was included as fixed effects. Estimated least squares means and corresponding SE are presented for the normally-distributed data. For the square root transformed data the backtransformed estimates are presented with a 95% confidence interval and for the poisson distributed data the backtransformed means and SE are presented. Statistical significance was accepted at $P \leq 0.05$ and $P \leq 0.10$ was considered a tendency.

3. Results

Two sows from the LC group were confined in crates too early and consequently they ended up in the CL group. The results are therefore based on 120 sows: 30 in the CC group, 32 in the CL group, 28 in the LC group and 30 in the LL group. The sows in the CC and CL groups were confined on day 114 of gestation which was 46.5 ± 3.30 h before birth of the first piglet. The sows in the LC group were confined 6.9 ± 0.9 h after the birth of the last piglet. For the CL sows the crate was opened 10.7 ± 1.3 h after birth of last piglet. The sows in the CC and LC groups were let loose 91.0 ± 1.23 h after birth of last piglet. Mean parity of the sows was 3.5 ± 0.18.

3.1. Farrowing progress

Results on litter characteristics and farrowing progress are presented in Table 1. Sows that were confined (CC and CL) and sows that were loose housed (LC and LL) before farrowing had similar number of total born piglets ($P = 0.69$), number of live born piglets ($P = 0.83$) and number of stillborn piglets ($P = 0.68$). As planned, there was no difference in equalized litter size between treatments ($P = 0.84$). Farrowing duration did not differ between confined and loose housed sows regardless if duration was measured as duration to last born piglet ($P = 0.26$) or last live born piglet ($P = 0.22$). Birth duration tended ($P = 0.09$) to be shorter for piglets born to loose housed sows, mainly because birth duration for stillborn piglets tended ($P = 0.06$) to be shorter in the loose housed

Table 1
Effect of confinement from day 114 of gestation to the end of farrowing on litter characteristics and farrowing progress. Litter characteristics are presented as estimates ± SE and values of farrowing progress are presented as backtransformed means (95% CI).

	Confined[a]	Loose-housed	*P*-value
Sows, *n*	62	58	
Litter characteristics			
Total born (no./l)	18.0 ± 0.47	17.8 ± 0.50	0.69
Stillborn (no./l)	1.0 (0.75; 1.27)	1.0 (0.80; 1.36)	0.68
Farrowing progress			
Farrowing duration			
BFP to BLP[b] (min)	462 (381; 552)	394 (316; 483)	0.26
BFP to BLL[b] (min)	413 (345; 486)	352 (287; 424)	0.22
Birth duration[c] (min)	259 (228; 293)	220 (190; 252)	0.09
Birth interval[d] (min)	23 (20; 26)	21 (18; 24)	0.25

[a] Treatment from day 114 of gestation to the end of farrowing.
[b] BFP = birth of first piglet, BLP = birth of last piglet, BLL = birth of last live born piglet.
[c] Time from birth of first piglet to birth of *n*th piglet.
[d] Time interval between two succeeding piglets.

sows (280 min (95% CI: 238; 325)) than in confined sows (347 min (95% CI: 301; 396)). The birth interval between two succeeding piglets did not differ between confined and loose housed sows ($P=0.25$). However, birth interval differed between live born and stillborn piglets in that live born piglets had an estimated birth interval of 15 min (95% CI: 14; 17) whereas stillborn piglets had a birth interval of 30 min (95% CI: 24; 35) ($P<0.001$).

3.2. Piglet mortality

Analysis of total piglet mortality before litter equalization (stillborn + live born dead) showed an interaction between treatment and farrowing duration ($P<0.001$) and this interaction tended to be present when stillbirth ($P=0.05$) and live born mortality ($P=0.06$) was considered separately (Fig. 3). Loose housed sows with short farrowings tended ($P=0.06$) to have fewer stillborn piglets than confined sows with short farrowing duration (< 5 h). Both the number of stillborn piglets and live born piglet that died before equalization increased with increasing farrowing duration for the loose housed sows ($P<0.05$) whereas this was not the case for the confined sows. Moreover, loose housed sows with medium (5–9 h) or long (> 9 h) farrowing durations had a higher number of live born piglets that died before equalization compared to confined sows with similar farrowing durations ($P=0.04$ and $P<0.01$, respectively).

Results on piglet mortality are presented in Table 2. Sows that were loose housed before and after farrowing (LL) had higher piglet mortality before equalization than sows in the other three treatments ($P<0.001$). During the first four days, after litters were equalized, mortality differed between treatments ($P<0.001$). The greatest mortality was observed in the loose housed groups (CL and LL) and the lowest were observed in the confined groups (CC and LC). There was a tendency ($P=0.10$) for sows that were confined after farrowing (CC and LC) to have more dead piglets from day 4 to day 7. The risk of dying from crushing differed between treatments ($P<0.001$).

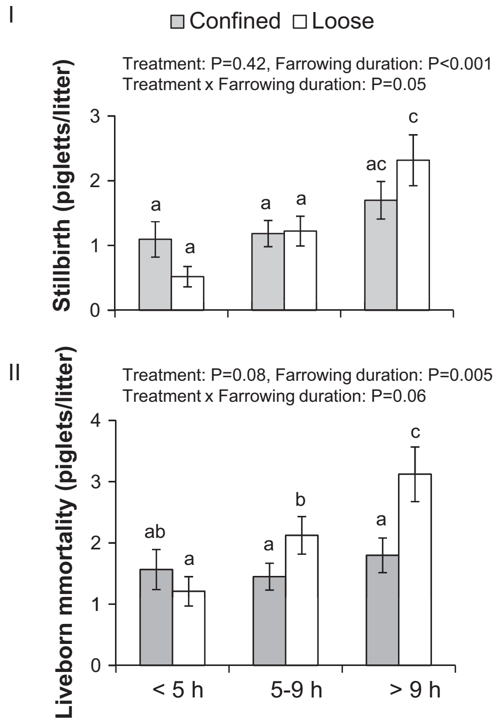

Fig. 3. Estimated (± SE) number of stillborn (I) and live born dead piglets per litter before equalization (II) in confined and loose housed sows with different farrowing duration. Different letters (a–c) indicate significant differences between columns at $P<0.05$. Number of sows with farrowing duration ' < 5 h', '5–9 h' or ' > 9 h': Confined: $n=17$, $n=27$ and $n=18$, Loose: $n=22$, $n=18$ and $n=16$.

Dead piglets were more likely to have died from crushing in the treatments where sows were loose housed for a period of time (CL, LC or LL) compared to those that died in the confined group (CC) ($P<0.001$). Compared to CC, the risk of being crushed was 3.5 times greater in CL ($P<0.001$), 4.3 times greater in LC ($P<0.001$) and 3.4 times greater in LL ($P<0.001$). There was no difference in the risk of dying from crushing between treatments CL, LC and LL. Additionally, the risk of dying from crushing was twice as high before litter equalization compared to the risk of dying of crushing after litter equalization ($P=0.02$).

3.3. Parity and litter size

Sow of parity 1–2 gave birth to fewer piglets than older sows (15.6 ± 0.55 vs. 20.1 ± 0.42; $P<0.001$), but parity 1–2 sows had fewer stillborn piglets (0.7 ± 0.14 vs. 1.5 ± 0.17; $P=0.001$) and consequently the number of live born piglets per litter was similar (parity 1–2: 16.7 ± 0.43; parity 3 or more: 17.1 ± 0.33, $P=0.50$). There were fewer live born piglets in small litters (7–18 piglets) compared to large litters (19–28 piglets) (14.2 ± 0.36 vs. 19.4 ± 0.39, $P<0.001$) and there were fewer stillborn piglets in small litters than in larger litters (0.7 ± 0.11; 1.5 ± 0.21, $P<0.001$). Sows that were parity 1–2 had shorter duration

Table 2
Effect of confinement before and after farrowing on piglet mortality to day 7. Values are presented as estimates ± SE.

Day 114 of gestation to end of farrowing (day 0)	Confined		Loose		*P*-value
Day 0 to day 4	Confined (CC)	Loose (CL)	Confined (LC)	Loose (LL)	
Sows, *n*	30	32	28	30	
Parity (no.)	3.4 ± 0.36	3.5 ± 0.35	3.5 ± 0.37	3.5 ± 0.36	0.99
Live born (no./l)	17.1 ± 0.48	16.6 ± 0.46	16.8 ± 0.50	17.1 ± 0.48	0.83
Mortality before litter equalization (%)	$5.0^{a} \pm 0.92$	$6.6^{a} \pm 1.06$	$5.7^{a} \pm 1.03$	$11.3^{b} \pm 1.44$	< 0.001
Equalized litter size (no./l)	13.3 ± 0.28	13.5 ± 0.27	13.3 ± 0.29	13.6 ± 0.29	0.84
Mortality from litter equalization to day 4 (%)	$5.0^{a,c} \pm 1.07$	$9.0^{b} \pm 1.39$	$3.2^{c} \pm 0.87$	$7.5^{a,b} \pm 1.31$	< 0.001
Mortality day 4 to day 7 (%)	4.9 ± 1.09	2.7 ± 0.77	3.8 ± 0.99	2.1 ± 0.69	0.10

[a–c] Values within a row with different superscripts differ significantly at $P < 0.05$.

of farrowing than sows of parity 3 or more (301 min (95% CI: 226; 387) vs. 577 min (95% CI: 493; 667); $P < 0.001$), also when duration was calculated as duration from birth of first piglet to birth of last live born piglet (291 min (95% CI: 227; 364) vs. 485 min (95% CI: 418; 557); $P < 0.001$). In line with this, the birth duration was shorter for piglets born to sows of parity 1–2 compared to piglets born to sows of parity 3 or more (202 min (95% CI: 171; 235) vs. 280 min (95% CI: 251; 310); $P < 0.001$). Birth interval tended to be shorter in sows of parity 1–2 than in parity 3 or older (20 min (95% CI: 16; 24) vs. 24 min (95% CI: 21; 27); $P = 0.09$), and birth interval was longer in small litters compared to larger litters (24 min (95% CI: 20; 28) vs. 20 min (95% CI: 17; 23); $P = 0.05$). The equalized litter size was greater for sows of parity 1–2 than older sows (13.8 ± 0.23 vs. 13.0 ± 0.18, $P = 0.004$). Sows of parity 1–2 had lower percentage piglet mortality than older sows before litter equalization (4.2 ± 0.77 vs. 10.9 ± 0.86; $P < 0.001$) as well as from litter equalization to day 4 (3.8 ± 0.76 vs. 8.6 ± 0.93; $P < 0.001$) and from day 4 to 7 (2.4 ± 0.60 vs. 4.4 ± 0.67; $P = 0.02$).

4. Discussion

In general, the results showed that confinement did not affect farrowing progress and no effect was seen in the number of stillborn piglets. On the other hand confinement before and after farrowing did reduce piglet mortality during the first four days after farrowing.

4.1. Farrowing progress

The estimated farrowing duration was 462 min for sows that were confined and 394 min for sows that were loose housed before and during farrowing. These findings are similar to the average durations of 417 min, 451 min, and 346 min that have recently been reported in Danish sows by Brandt et al. (2012). However, it is longer than what has generally been presented in the scientific literature. When comparing farrowing duration in confined and loose housed environments, the reported durations varied between 174–311 min for sows in crates and 146–218 min in pens (Jarvis et al., 2004; Oliviero et al., 2008; Thodberg et al., 2002).

In this study, sows were classified according to the duration of farrowing and since a large proportion of sows had very long farrowings (> 9 h), it was decided to report the consequences of these farrowings. In previous studies the majority of sows finished farrowing within 4–5 h (e.g. Oliviero et al., 2008, 2010), which was also the case in Tummaruk and Sang-Gassanee (2013) where only 15% of the sows had duration of more than 4 h. Oliviero et al. (2008) suggested that farrowings with duration of more than 4 h should be considered long and in Oliviero et al. (2010) farrowing lasting for more than 5 h was proposed to be long farrowings. However, these classifications were based on the distribution of farrowing length in those studies, and applying these classifications to the current data would yield a much skewed distribution that would not be useful in any analysis. Similar to others, we therefore classified sows according to the duration of farrowing in our study. Because such a large proportion of sows in our study had really long farrowings (> 9 h), we found it necessary to report the consequences of these farrowings and not just farrowings > 5 h.

Breed can affect the duration of farrowing (van Dijk et al., 2005) and the differences between studies can therefore likely be attributed differences in genetic background of the sows. In addition, the current study supported previous findings that litter size can influence duration of farrowing (Herpin et al., 1996) and birth interval (Baxter et al., 2009; Damm et al., 2005). The large litter sizes are therefore a likely cause of the longer farrowing duration in our study. Similar to our study, Oliviero et al. (2008, 2010) included sows of parity 1–7, but in contrast to our results, crated sows had prolonged farrowing and longer birth intervals compared to loose housed sows in pens. Unlike Oliviero et al. (2008, 2010), who only supplied nesting material to sows in pens, we provided confined and loose sows with equal amounts and type of nest building material. Type and accessibility of nest building material can influence the progress of farrowing (Jarvis et al., 2004; Thodberg et al., 1999) and effects of confinement and nest building material might therefore be confounded in Oliviero et al. (2008, 2010). The pens in our study only differed in whether or not the swing-side crate was closed or open, thus available space was the only difference between the confined and loose housed sows. In accordance with Jarvis et al. (2004) and Cronin et al. (1994), our results suggest that increased space and ability to move around in itself did not lead to differences in farrowing duration. Thodberg et al. (2002)

found that confinement increased farrowing duration as well as birth interval for first parity sows, but not for second parity sows, and similar results were obtained by Pedersen and Jensen (2008). Thodberg et al. (2002) suggested that first parity sows may be more sensitive to environmental influence as they have not previously experienced the farrowing situation or the farrowing environment. However, Jarvis et al. (2004) did not find the same effect of environment on gilts housed in crates and pens. Parity 1 and 2 sows were grouped together in this study and this could mask an effect of confinement on farrowing progress of parity 1 sows if confinement only had an effect on parity 1 sows. It is worth noticing, that in most of the previous studies of the effect of confinement on farrowing progress, sows have been confined for various periods before farrowing. Whereas the sows in some studies are placed in the farrowing facility approximately 5–7 days before expected farrowing (Cronin et al., 1994; Jarvis et al., 2004; Thodberg et al., 2002), in others the sows are placed in their farrowing accommodation approximately 14–20 days before expected farrowing (Oliviero et al., 2008, 2010). The sows in our study were loose housed until day 114 of gestation meaning that they were confined for much shorter period than the confined sows in any of the other studies.

The aim of this study was to evaluate the effect of temporary crating in a housing system where the sows could be loose housed and not to compare placement in farrowing crates with housing in farrowing pens. Day 114 was chosen as day of confinement to ensure that sows were loose as much as possible and still safeguarding that sows that should be confined before farrowing would in fact be confined for some time (average 47.5 h) before birth of the piglets. There are physiological, behavioral and endocrinological adaptation processes occurring in sows during the last week of pregnancy, including nest building behavior that are greatly affected by confinement as previously reported in the literature (e.g. Damm et al., 2005; Jarvis et al., 2001; Thodberg et al., 2002). These studies have therefore applied the treatment (confined vs. open pen) at least one week prior to farrowing. In traditional farrowing crates the only option is to keep sows confined from placement in the farrowing crate until weaning even though farrowing and lactating sows are confined to protect the piglets and therefore no need to confine sows until immediately after the piglets are born.

In the present study, stillborn piglets were born after a longer birth interval than live born piglets. Longer birth intervals have previously been related to stillbirth, which is likely due to increased risk of asphyxia during delivery (Pedersen et al., 2006; van Dijk et al., 2005; Zaleski and Hacker, 1993). Prolonged farrowing has also been related to stillbirth (Oliviero et al., 2010; Thodberg et al., 2002) but prolonged farrowing only seemed to affect loose housed sows in the current study. In accordance with Malmkvist et al. (2006), live born mortality amongst loose housed sows was, however, also affected by duration of farrowing. Asphyxiation may cause poor viability of the live born piglets, increase latency to reach the udder and increase live born mortality (Herpin et al., 1996; Zaleski and Hacker, 1993). In a loose housed system where the risk of crushing might be greater than in a confined system, the consequences of having suffered from asphyxia might be more detrimental than in confined systems.

4.2. Piglet mortality

Results on piglet mortality showed that there was an increased mortality in loose housed sows compared to sows that were confined for the first four days after farrowing. These findings are in accordance with previous results from our group using a different pen design (Moustsen et al., 2013), also showing that confining sows for the first four days could reduce piglet mortality compared to loose housed sows.

From litter equalization to day 4 the highest mortality rates were found in CL and LL, whereas there was no difference between groups from day 4 to 7. A higher mortality in loose housed sows is in agreement with some studies of piglet mortality in farrowing pens (e.g. Hales et al., 2014; Marchant et al., 2000) but in contrast to others (e.g. Cronin et al., 2000; Weber et al., 2007). It was moreover seen from the post mortem examinations that the risk of crushing was higher when sows were loose housed at some point during the experimental period, compared to the CC group. Baxter et al. (2011) suggested that alternative farrowing systems should be fitted with features to protect piglets from crushing, such as sloped walls. In this study the sides of the crate was fitted with a farrowing rail, but no other protection features were present. If the loose housed sows preferred to use support when lying down, they only had the option of using the sides of the crate or the vertical wall at the slatted floor. Considering that sows have shown preferences for lying down against a surface and preferably a sloped wall (Damm et al., 2006; Marchant et al., 2001) the design of the pen in our study could have had a negative impact on sow behavior and control during lying down events, resulting in an increased risk of crushing of the piglets. Both the increased risk of crushing and increased mortality in loose housed groups could therefore be a result of inadequate design of the pen. Results from the post mortem examinations moreover showed that the risk of dying from crushing was greater before litter equalization but this was likely related to larger litter size in this period. Larger litter size increases mortality due to crushing as well as other reasons (Pedersen et al., 2006; Roehe and Kalm, 2000; Weber et al., 2007) and the presence of more piglets in the pen increases the risk of a sow crushing one when lying down (Weary et al., 1998).

Interestingly, mortality from day 4 to day 7 tended to be higher in CC compared to LL even though sows in all treatment were loose during this period. This could indicate that in the confined group, some of the weaker piglets were protected by the crate leaving them more susceptible to crushing when the crate was opened. Piglets that tend to stay close to the sow to gain udder access are more susceptible to crushing (Weary et al., 1996b) and in loose systems the consequences of such risky behavior may be even greater. It can be speculated if behavior of the sows was affected when the crate was opened, possibly because the sows had to 'learn' to lie down without the restrictions of the crate. The response of sows and piglets when the crates were opened was not part of this study. Nonetheless, it would be relevant to address in future studies if the opening of the crate has consequences for sow behavior and piglet mortality.

4.3. Parity and litter size

Younger sows in this study had shorter farrowing duration, birth duration and birth intervals, which is probably because younger sows gave birth to smaller litters (Herpin et al., 1996; Pedersen et al., 2006). In addition, younger sows had lower piglet mortality in all observational periods. This is in accordance with previous studies where piglet mortality has increased with parity (Hales et al., 2014; Jarvis et al., 2005). Mortality was calculated as a relative measure to eliminate the importance of the size of the litter. However, it is interesting that younger sows were equalized to larger litters and had lower piglet mortality. This indicates that parity in itself is of importance for piglet survival, and not only because older sows give birth to larger litters with smaller piglets.

5. Conclusion

Confinement from day 114 of gestation and during farrowing did not affect farrowing progress compared to sows that were loose housed before and during farrowing. Piglet mortality did on the other hand depend on housing system and the results suggested that confinement of sows for four days after farrowing reduced mortality compared to sows that were loose housed.

Conflict of interest statement

There are no conflicts of interest to the submitted manuscript entitled 'Comparable farrowing progress in confined and loose housed hyper-prolific sows'.

Acknowledgements

The project was funded by the Pig Levy Foundation, The Danish Rural Development Program 2007-2013/The European Agricultural Fund for Rural Development (Jnr 3663-D-10-00458) and the Department of Large Animal Sciences, University of Copenhagen. The authors would like to thank the staff at Graasten Landbrugsskole for all their hard work and cooperation during this experiment. We would also like to thank Ann Edal and Hanne Nissen for their help with data collection and Kenneth Damholt Kristensen for technical support with the video recording.

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Paper III

Temporary confinement of loose housed hyper prolific sows reduces piglet mortality

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Manuscript submitted for publication

Temporary confinement of loose housed hyper prolific sows reduces piglet mortality[1]

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[1] This project was funded by the Danish Pig Levy Foundation and The Danish Rural Development Program 2007-2013/The European Agricultural Fund for Rural Development (Jnr 3663-D-10-00458). We would like to acknowledge the technicians Mogens Jakobsen (Pig Research Centre) and Jens Ove Hansen, for their assistance in data collection. We would also like to thank everyone at Krannestrup for their collaboration and participation in the study.

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ABSTRACT: The objective of this study was to investigate piglet mortality in a commercial setting where sows were accommodated in a loose housed system with an option to confine the sow for a few days around farrowing and during early lactation. The study was conducted in a Danish piggery where records were obtained from 2,139 farrowings. Sows were randomly allocated to 1 of 3 treatments: Loose-Loose (LL), Loose-Confined (LC) and Confined-Confined (CC). In LL sows were loose housed from the time they entered the farrowing pens to weaning. In LC sows were loose housed until farrowing was finished and then confined to d 4 after farrowing. In CC sows were confined at d 114 of gestation to d 4 after farrowing. All sows were loose housed from d 5 to weaning. Total piglet mortality was analyzed at batch level to include piglets fostered by nurse sows and at sow level to analyze the effects of confinement during different time periods. Total piglet mortality was greater in LL (26.0 %) and LC (25.4 %) compared to CC (22.1 %) ($P < 0.001$). The proportion of stillborn piglets was not different between treatments ($P = 0.21$), but a larger proportion was crushed in LL (10.7 %) compared to LC (9.7 %; $P = 0.03$), which again was greater than CC (7.8 %; $P < 0.001$). Piglet mortality before equalisation was lower in CC (3.7 %) than in LL (7.5 %) and LC (7.0 %) ($P < 0.001$). Confinement reduced mortality from litter equalisation to d 4 (LL: 7.6 % vs. LC: 6.7 %; $P = 0.01$), but more so in CC (5.6 %) than in LC ($P < 0.001$). From d 4 to weaning LL had lower mortality (5.6 %) than LC (6.9 %) and CC (6.6 %) ($P = 0.01$). A larger proportion of sows in CC were classified as 'low mortality' compared to LL and LC both before ($P < 0.001$) and after ($P = 0.002$) litter equalisation. The results in this study emphasizes that the period of time from the birth of the first piglet to litter equalisation is important in relation to piglet mortality. The results also suggest that confinement for 4 d after farrowing can reduce mortality in this specific period, but confinement from before farrowing was necessary to reduce piglet mortality satisfactorily.

Key words: Farrowing, housing, lactation, loose sows, piglet mortality, temporary crating

INTRODUCTION

The farrowing crate is used to physically restrict the sow from moving around and thereby reduce crushing of the piglets but the restriction also prevents the sows from performing behaviors associated with nest building, farrowing and lactation (Damm et al., 2003; Jarvis et al., 2004). The negative impact on sow welfare has led to the development of alternatives such as designed farrowing pens (Baxter et al., 2012), but variability and inconsistency in piglet mortality has limited commercial uptake of these systems (Arey, 1997; Baxter et al., 2012). Piglet deaths mainly occur in the first days of life (Marchant et al., 2000), indicating that piglets need protection in this period. Confinement of sows in early lactation can reduce piglet mortality compared to loose housed sows (Moustsen et al., 2013; Hales et al., 2015), but the pens in these studies did not contemplate with the design criteria proposed for loose farrowing and lactating sows by Baxter et al. (2011). Consequently, the Sow Welfare And Piglet protection pen (**SWAP pen**) was developed by incorporating a confinement option into a designed farrowing pen for loose sows. Genetic improvements have increased litter size, e.g. in Denmark where average litter size is 16.6 total born piglets (Rutherford et al., 2013). Large litters require management interventions like the use of nurse sows for surplus piglets to rear all piglets successfully (Baxter et al., 2013). Studying piglet mortality should therefore not only be conducted on sow level but also on batch level and include piglets reared by nurse sows and moved between sows. Assessment of piglet mortality is therefore best studied in commercial settings. The objective of this study was to investigate piglet mortality in a commercial setting where sows were housed in a system with an option to confine the sow. The hypothesis tested was that confinement of sows for 4 d after farrowing in SWAP pens would reduce piglet mortality compared to loose housed sows.

MATERIALS AND METHODS

The study was conducted in a newly constructed 1,250 sow piggery (Krannestrup, Mejlby, Denmark) with Danish Landrace x Danish Yorkshire sows farrowing in weekly batches. All procedures involving animals were conducted in accordance with the guidelines of the Danish Ministry of Justice with respect to animal experimentation and care of animals under study.

Experimental design

Sows were allocated to 1 of 3 treatments: loose-loose (**LL**), loose-confined (**LC**) or confined-confined (**CC**) (Figure 1). Sows in LL were loose housed from entry to the farrowing unit to weaning after 4 wk of lactation. In LC sows were loose housed from entry to completion of farrowing (birth of placenta). At first observation of completed farrowing sows were confined until d 4 after farrowing. In CC sows were loose housed at entry and confined from d 114 of gestation until d 4 after farrowing. On d 4 the confinement was removed and sows in LC and CC were loose housed for the remaining of lactation.

First parity sows were randomly allocated to 1 of the 3 treatments and would (as much as possible) return to the same system for the following farrowings. Batches of first parity sows were furthermore grouped together according to expected farrowing dates (to facilitate cross fostering within treatments) and the farrowing date groups were then randomly allocated to 1 of the 3 treatments.

Housing

During mating and gestation sows were housed in stable groups of 50 to 60 sows corresponding to the size of a weekly batch. Sows were moved to the farrowing unit where they were placed in individual SWAP pens 4 to 7 d before expected farrowing. The farrowing unit consisted of 5 identical rooms, each with 58 farrowing pens, and 2 buffer sections with 29 farrowing pens each. The desired room temperature in the farrowing unit was 18 to 21 ºC. This was controlled via diffuse ventilation with supplemental air inlets in the ceiling in combination with partial pit ventilation. Artificial light was on from 0700 to 1600 h in all farrowing rooms.

The SWAP pens (Figure 2) measured 210 x 300 cm and the flooring consisted of 60 % solid concrete floor and 40 % cast iron slats (> 40 % void). The concrete floor was equipped with 3 different circuits for floor heating: 1 in the creep area for the piglets, 1 in the resting area for the sow and 1 in the inspection aisle to prevent heat loss from the creep. The creep was placed adjacent to the aisle and had an adjustable lid. The trough and drinker for the sow was placed next to the creep and there was a piglet drinker above the slatted floor. All pens were fitted with a straw rack on the gate and a sloped wall in the intended resting area to support the sow when lying down (Damm et al., 2006) as well as an open (barred) pen partition from the sloping wall to the back wall to facilitate dunging behavior. The pens had farrowing rails on the back wall and on the wall between the trough and the back wall. The front of the creep formed a swing-side that was hinged on the front wall of the pen and folded out to form the option of temporary confinement with the sloped wall as the opposite side. The swing-side was made up of 2 metal frames with horizontal bars and seven vertical 'fingers' at the bottom. A back gate was placed in a bracket between the pens. An additional trough and drinker was placed on the gate to provide feed and water when the sows were confined.

In the first days after parturition saw dust was spread in the creep area as bedding material and for the first 4 d of lactation a 150 W heat lamp was provided in the covered part of the creep area. Floor heat (~ 42 °C) in all areas was on when the sows entered the pens. Heat in the sow area was generally on for 4 d after the main day of farrowing whereas the floor heat in the creep area and the aisle was on from insertion to weaning.

Animals and management

All animals in this study were managed according to the general routines of the herd. The study involved 1,125 sows of parity 1 to 4. All sows were artificially inseminated with production semen from Duroc boars (Hatting KS, Horsens, Denmark) and fed in agreement with Danish recommendations (Tybirk et al., 2014). In the gestation period the animals were fed once a day in electronic sows feeders according to parity and body condition. The gestation diet was based on wheat, barley and soybean meal and contained 8.2 MJ potential physiological energy/kg feed (Boisen, 2001) and 5.3 g standardized ileal digestible Lys/kg feed. In the farrowing unit sows were fed a lactation diet 3 times per day (0730, 1230 and 1530 h). The lactation diet was based on barley, wheat and soybean meal and contained 8.7 MJ potential physiological energy/kg feed (Boisen, 2001) and 7.5 g standardized ileal digestible Lys/kg feed. Before farrowing the sows received a total of 3.7 kg feed/d. The ration was reduced to 2.7 kg/d 2 d before expected farrowing and increased to 3.2 kg feed/d on d 2 after farrowing. The following days, the feed ration was increased by 0.5 kg feed/d to d 6 and hereafter by 0.5 kg feed/d every second day, provided that sows had emptied the troughs. After approximately 14 d the number of feeding times was increased to 5 times per day (0730, 1030, 1230, 1530 and 2030 h). Sows and piglets had *ad libitum* access to water via drinking nipples throughout the period from placement in the farrowing pens to weaning.

Straw was provided in straw racks from placement of sows in the farrowing pens to weaning. Staffs were generally present from 0700 to 1600 h every day and carried out regular rounds through the farrowing unit to inspect sows that had farrowed. Obstetric aid was performed when deemed necessary. On d 1 piglets were inspected, dry umbilical cords were cut off and piglets were injected with 0.5 mL antibiotics (Clamoxyl Prolongatum, Orion Pharma Animal Health, Nivaa, Denmark). Litters were equalised within treatments to 13 to 14 piglets by cross fostering piglets born within the same 12 to 24 h when it had been ensured that all piglets had consumed colostrum. On the first 2 d after farrowing, piglets were closed inside the creep area during feeding. Tail docking, the injection of iron (Solofer, Vitfoss, Gråsten, Denmark) mixed with pain relief (0.2 ml per pig, Melovem, Salfarm Denmark, Kolding, Denmark), oral administration of Baycox (Bayer A/S, Copenhagen, Denmark) and surgical castration were all performed on d 3. Piglets were weaned from the sow at 4 wk. Piglets that were traumatized or diseased, or for other reasons deemed unable to survive to weaning, were humanely euthanized.

Records

The date of insertion in the farrowing unit, the date and time of the first observation of farrowing, the number of live born and stillborn piglets as well as date and time of closing and opening of confinement was noted on a sow card. If obstetric aid was performed or if sows were treated with antibiotics it was also recorded on the sow card. When litters were equalised the date and time of the procedure was recorded as well as the size of the litter when the procedure was completed. Dead piglets were collected from each sow on a daily basis. At collection, dead piglets from the same pen were bagged together with an ear tag, and date and tag number was recorded on the sow card. If piglets were moved between sows, within treatment, the number removed or added was noted. Piglets that were moved to a nurse sow were tagged according to treatment and nurse sows were housed according to the treatment the piglets came from. Thus nurse sows for piglets from LL were loose housed and nurse sows for piglets from LC or CC were confined until the piglets were 4 d old and then loose housed from d 4 to weaning.

Postmortem examination

All piglets that died before weaning were stored at -2 °C until they were weighed and subjected to postmortem examination to confirm the cause of death. Postmortem examinations were carried out on a weekly basis. Stillbirth was determined by inflation of the lung tissue. If the lung tissue would not float in water the piglet was categorized as 'stillborn'. Piglets were categorized as 'crushed' if there were obvious signs of trauma or subcutaneous edema or both in any part of the body. Live born piglets that did not display signs of crushing and had not received colostrum as well as piglets that were euthanized by the staff were classified as 'euthanized or weak'. Piglets that died from disease and piglets that could not be accurately classified at the postmortem examination were categorized as dead from 'other causes'. The stomach contents of the dead piglets were evaluated as 'empty', 'less than half full', 'more than half full', and 'full'.

Statistical analyses

Statistical analyses were performed using SAS ver. 9.3 (SAS Institute Inc., Cary, NC) with batch or sow as the experimental unit. Statistical significance was accepted at $P < 0.05$ and $P < 0.10$ was considered a trend. For analyses of system performance on batch level; the number of farrowings, total born piglets, percent stillborn piglets, percent of piglets fostered by nurse sows in a batch (piglets fostered by nurse sows / live born), total mortality ((stillborn + live born dead) / total born), live born mortality (live born dead / live born) and percent crushed piglets (crushed / total born) was analyzed using the MIXED procedure of SAS with treatment (LL, LC or CC) as fixed effect and batch as random effect. The distributions of cause of death in the 3 treatments (LL, LC, and CC) were analyzed using a chi-square test. Percent live born piglets that died with empty stomachs (empty stomach / necropsied piglets) was analyzed by use of the GLIMMIX procedure with an underlying binomial distribution and treatment (LL, LC or CC) as fixed effect and batch as random effect.

Analysis of sow performance was conducted on the farrowing sows. Sow parity was analyzed with treatment as fixed effect and batch as random term. Data on total born, live born, equalised litter size and weaned piglets were normally distributed and analyzed using the MIXED procedure with treatment (LL, LC or CC), parity (parity 1, parity 2 or parity 3 to 4), and the corresponding interaction term as fixed effects and batch as random effect. The number of stillborn piglets per litter was discrete and analyzed using the GLIMMIX procedure to fit a linear model with an underlying poisson distribution and treatment and parity as fixed effects, batch as random term, total born as covariate and the corresponding interaction terms. Piglet mortality before equalisation (live born piglets that died before equalisation / live born), from equalisation to d 4 (live born that died from equalisation to d 4 / equalised litter size), and from d 4 to weaning (live born that died from d 4 to weaning / equalised litter size) was analyzed by use of the GLIMMIX procedure for binomially distributed data and treatment, parity and the interaction term as fixed effects, batch as random term and a litter size indicator (total born for analysis before litter equalisation and equalised litter size after equalisation) as covariate. Sows were categorized as 'low mortality' or 'high mortality' according to the mortality rate before litter equalisation and from equalisation to d 4. Sows were considered low mortality if they had 0 to 1 dead piglets and high mortality if they had 2 or more dead piglets. The proportion of low mortality sows in each of the 2 periods were analyzed in a linear model with an underlying binomial distribution and treatment and parity as fixed effect, a litter size indicator (total born for analysis before litter equalisation and equalised litter size after equalisation) as covariate, the corresponding interaction terms and batch was included as random term. Non-significant interaction terms ($P > 0.05$) were removed from the models. Results on normally distributed data are presented as estimates ± SE and results on poisson and binomially distributed data are presented as back-transformed estimates with 95 % CI.

RESULTS

The results of this study are presented at batch level to allow for comparison of total piglet mortality between the 3 systems LL, LC and CC. Subsequent results on effects of confinement during different time periods and the effects of sow factors are presented at sow level. In 5 batches 1 or more treatments had to be excluded from the analyses of production systems due to insufficient quality of the data. For the analyses of sow performance 131 sow cards were excluded because of insufficient data quality. Sows in CC were confined on d 114.1 ± 0.01 of gestation and were confined for 72.1 ± 1.14 h before farrowing. Sows in CC stayed confined for 96.3 ± 0.55 h after farrowing and consequently, the total time in confinement for CC sows was 168.4 ± 1.22 h. Sows in LC were confined at 2.1± 0.05 h after farrowing was finished and were confined for a total of 95.0 ± 0.57 h.

Production systems

Results on performance at batch level are presented in Table 1. There were 11.8 ± 0.10 farrowings and the number of total born piglets averaged 213.9 ± 2.42 piglets per batch with no difference between treatments ($P = 0.29$). Approximately 20 % of live born piglets in a batch were fostered by nurse sows. In LL the ratio of piglets that were fostered by nurse sows was smaller than the proportion fostered by nurse sows in LC (18.9 % vs. 21.1 %; $P < 0.01$).

Total piglet mortality was reduced in CC compared to LL and LC ($P < 0.001$). The percent stillborn piglets did not differ between treatments (5.4 ± 0.20; $P = 0.21$), but percent crushed piglets (of total born) was greater in LL compared with LC ($P = 0.03$) and further decreased from LC to CC ($P < 0.001$). Live born piglet mortality followed the pattern of total mortality with lower mortality in CC compared to LL and LC ($P < 0.001$). The distribution of cause of death of live born piglets that died before weaning differed between treatments ($P < 0.001$). In all treatments, the majority of live born deaths were attributed to 'crushing' (LL: 59.5 %, LC: 55.3 %, CC: 53.9 %), followed by 'other' (LL: 21.2 %, LC: 23.1 %, CC: 27.2

%) and 'euthanized/weak' (LL: 19.3 %, LC: 21.6 %, CC: 18.9 %). More than half of live born deaths were associated with empty stomachs but more so ($P < 0.001$) in LC where 60.5 % (57.9; 63.0) of autopsied piglets had empty stomachs compared to LL and CC where 53.3 % (50.7; 55.9) and 52.7 % (49.9; 55.5), respectively, had empty stomachs.

Sow performance

Results on sow performance are presented in Tables 2 to 4. The average parity of the farrowing sows was 2.3 ± 0.02 with a gestation length of 116.8 ± 0.03 d. Total born litter size averaged 18.3 ± 0.07 piglets per litter. Sows in LL had fewer live born piglets than sows in LC ($P = 0.005$) and CC ($P = 0.044$) and sows in LL had more stillborn piglets per litter than sows in LC ($P = 0.027$) and CC ($P = 0.016$). Treatment tended to influence the size of the equalised litter (13.7 ± 0.03; $P = 0.06$), however with only a difference of 0.1 piglet/litter. Piglet mortality before litter equalisation was greater in LL and LC compared to CC ($P < 0.001$). Treatment also influenced mortality from equalisation to d 4 ($P < 0.001$) where LL had a greater mortality rate than LC ($P = 0.01$), which again had a greater mortality than CC ($P = 0.002$). Mortality from d 4 to weaning was greater in the treatments where sows had been confined (LC and CC) compared to LL ($P = 0.01$). The sows that were weaned at 4 wk in LL weaned more piglets compared to LC (LL: 11.4 ± 0.10, LC: 11.1 ± 0.10; $P = 0.01$). Weaned piglets per litter in CC (11.3 ± 0.11) did not differ from LL or LC. A greater proportion of sows in CC were categorized as 'low mortality' compared to LL and LC before litter equalisation ($P < 0.001$) as well as from equalisation to d 4 ($P = 0.002$).

With increasing parity the number of total born piglets ($P < 0.001$), live born piglets ($P < 0.001$), and stillborn piglets ($P < 0.01$) increased and the number of stillborn deaths also increased with increasing litter size ($P < 0.001$). Equalised litter size decreased with increasing parity ($P = 0.001$) but increased with increased number of live born ($P < 0.001$). Mortality before equalisation was not affected by parity ($P = 0.08$), but increased with increasing number of live born ($P < 0.001$). From equalisation to d 4 mortality increased with increasing parity ($P < 0.001$) and parity 2 sows tended to have a lower mortality from d 4 to weaning than sows of parity 1 and parity 3 to 4 ($P < 0.10$). From d 4 to weaning mortality furthermore increased with increasing size of the equalised litter ($P < 0.001$). The proportion of 'low mortality' sows decreased with increasing litter size before litter equalisation ($P < 0.001$) and with increasing equalised litter size ($P < 0.001$) after equalisation.

DISCUSSION

The main objective of this study was to investigate piglet mortality in a system where sows could be confined for a few days after farrowing compared to loose housed sows. In general, the results showed that confinement from gestation d 114 to d 4 after farrowing reduced piglet mortality and that this reduction to a large extent was achieved because fewer piglets died before litter equalisation. Confinement after farrowing did reduce mortality in some periods compared to loose housed sows, but confining sows after farrowing did not lead to satisfactory improvements in performance.

Total mortality and live born mortality were higher in this study, even though reduced when sows were confined before farrowing, than the numbers reported in other studies concerning loose lactating sows (Weber et al., 2007; KilBride et al., 2012). However, compared to records from other Danish herds (with traditional farrowing crates) where total mortality is around 22 to 23 % (Vinther, 2014) the levels in this study seem comparable, especially in the treatment where sows were confined before farrowing. The novelty of the pens (which meant that the staff had no experience with the system) could have had a negative influence on mortality in this study. However, the association between increased litter size and increased mortality is well-documented (Roehe and Kalm, 2000; Weber et al., 2009; Hales et al., 2014) and the large litter size of approximately 17 live born piglets should also be considered a risk factor in comparison with other large scale studies where the average litter size has been around 11 live born piglets (Weber et al., 2007; KilBride et al., 2012). Consequences of large litter sizes include increased farrowing duration and greater risk of asphyxia, decreased viability of the newborn piglets, decreased birth weight, increased within litter weight variation and increased teat competition (Herpin et al., 1996; Wolf et al., 2008; Andersen et al., 2011). Thus, the consequences of large litter sizes has likely increased the proportion of newborn piglets that had increased risk of dying, and this might also explain the greater piglet mortality in in this study. In addition, this highlights the importance of including all piglets when studying piglet mortality in hyper-prolific sows under conditions where management interventions like cross fostering and the use of nurse sows is part of the normal management routines. The proportion of piglets fostered by nurse sows has not previously been reported in scientific literature, but the quantity of approximately 20 % in this study corresponds to standard practice and experiences in commercial piggeries in Denmark.

Confinement from d 114 of gestation to d 4 after farrowing generated the lowest mortality. Confining sows from the end of farrowing did not benefit mortality before equalisation, which was similar to reports by Moustsen et al. (2013) but in contrast to another study investigating effects of temporary confinement on piglet mortality (Hales et al., 2015). The first 2 h after onset of farrowing have been associated with more postural changes by sows and increased risk of crushing compared to the rest of the farrowing process and the time around farrowing can be considered a risky period in relation to piglet mortality (Weary et al., 1996; Pedersen et al., 2003). Moreover, for sows that finished farrowing during the night, there was a time lag from the actual end of farrowing until sows were confined. The fact that the sows that were confined after farrowing were loose housed during farrowing and in some cases also for a period of time after farrowing, can explain why mortality before equalisation were similar to loose housed sows. However, confinement after farrowing did reduce mortality from equalisation to d 4 compared to loose housed sows, but not to the same extent as confinement before farrowing did. Previous results have also shown a reduction in piglet mortality when sows were confined for 4 d after farrowing, but none of these studies reported a difference in mortality between confinement before farrowing and confinement after farrowing (Moustsen et al., 2013; Hales et al., 2015). The option of confinement in this study was somewhat different from a traditional farrowing crate and pen design used in previous experiments, but was designed to decrease the risk of crushing by protecting the piglets when the sow lay down. Crates have previously been shown to prevent the sows from performing dangerous movements or slow down the speed of these movements (Weary et al., 1996; Damm et al., 2005). In the current study crushing accounted for more deaths in the loose housed sows compared to the other treatments, indicating that confinement did reduce the risk of crushing. This is in accordance with other studies showing an increased risk of crushing when sows were loose housed (Weary et al., 1996; Weber et al., 2007). However, results from the postmortem examinations showed that more piglets died with empty stomachs if sows were confined after farrowing, indicating that nursings might have been affected in this treatment. Sows that were confined before farrowing had a few days to get used to the confinement whereas sows that were confined after farrowing had to get used to the confinement as well as recover from farrowing. Confinement after farrowing could be seen as an environmental disturbance, which has previously been shown to interrupt the farrowing process (Lawrence et al., 1992), but it is unknown if and how such an environmental disturbance after farrowing affects the sows.

Piglet mortality from d 4 to weaning was greater for sows that had been confined than for sows that had been loose housed. As suggested by Hales et al. (2015), confinement might protect weak piglets in a litter, which leaves them at greater risk when the sow is no longer confined. Another aspect is that due to the greater mortality to d 4, the number of piglets left in the pen was lower, which decreases the risk of crushing (Weary et al., 1998). Further studies on temporary crating of sows should include investigations into sow behavior when the sow is no longer confined to elucidate if this period should be in focus in relation to piglet mortality and for how long any alterations in behavior might be seen.

A larger proportion of the sows that were confined before farrowing had low mortality, both before and after litter equalisation as compared to the other 2 treatments. In comparison with previously reported results where less than 50 % of sows were classified as low mortality (Hales et al., 2014), the proportion of sows with low mortality was generally high. Because this study was conducted in a newly built herd, the sows in this study were relatively young and this distribution across younger parities could have influenced the results as an increase in parity has been shown to increase preweaning mortality (Jarvis et al., 2005; Weber et al., 2009). In this study first parity sows had lower mortality than sows of parity 2 and sows of parity 3 to 4 from litter equalisation to d 4. First parity sows are smaller and lighter than older sows, which could influence their ability to stand and lie down in a controlled way, and they have likewise been found to be more responsive to piglet distress calls (Hutson et al., 1992). First parity sows also have shorter duration of farrowing than older sows (Tummaruk and Sang-Gassanee, 2013), indicating that the physical strain of the farrowing process is prolonged and harder to recover from in older sows.

The design of the SWAP pen incorporated to a large extent the recommendations for pen design proposed by Baxter et al. (2012) and was planned to provide the newborn piglets with a thermally adequate environment and protect them from crushing by the sow. Without the option of confinement, the production results in these pens were not satisfactory compared to traditional crates (Hales et al., 2014), but the outcome from this study show that by use of a strategy for temporary confinement, piglet mortality can be improved considerably. However, this questions the need for confinement throughout lactation as it is practiced in traditional farrowing crates.

In conclusion, the results from the current study highlight the importance of the time from birth to litter equalisation when discussing piglet mortality, and suggest that confinement of sows when the last piglet is born does not improve perinatal mortality. Confinement for the first 4 d of lactation did reduce piglet mortality in that period, but the lowest piglet mortality was achieved when sows were confined before farrowing and for 4 d after farrowing suggesting that live born piglets are at risk also during the farrowing process. Based on the current study temporary confinement of sows for a short period around farrowing seems necessary to reduce piglet mortality.

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Table 1. Performance results on batch level for loose housed sows and sows that had been confined for the first 4 d of lactation according to 2 different strategies of confinement. Values presented as estimates ± SE.

	Loose-Loose (LL)	Loose-Confined (LC)	Confined-Confined (CC)	SE	*P*-value
Batches, n	58	56	59		
Farrowings/batch	12.0	11.8	11.5	0.18	0.10
Total born, n/batch	213.6	218.3	210.2	4.18	0.29
Piglets fostered by nurse sows, %	18.9[a]	21.1[b]	19.7[ab]	0.97	0.04
Total mortality, %[1]	26.0[a]	25.4[a]	22.1[b]	0.64	< 0.001
Stillborn, %[2]	5.8	5.2	5.2	0.35	0.21
Crushed piglets, %[2]	10.7[a]	9.7[b]	7.8[c]	0.53	< 0.001
Live born mortality, %[1]	21.4[a]	21.4[a]	17.9[b]	0.57	< 0.001

[a,b] Values with different superscripts differ significantly, $P < 0.05$.

[1]Total mortality=(stillborn+live born dead)/total born, live born mortality=live born dead/live born.

[2]Calculated as percent of total born.

Table 2. Reproduction and piglet mortality for loose housed sows and sows that had been confined for the first 4 d of lactation according to 2 different strategies of confinement. Values are presented as estimates ± SE or back-transformed estimates and 95 % CI.

	Loose-Loose (LL)	Loose-Confined (LC)	Confined-Confined (CC)	SE	*P*-value
Number of sows	682	668	658		
Parity	2.2	2.2	2.2	0.09	0.18
Gestation length, d	116.8	116.8	116.9	0.06	0.32
Litter size, no					
Total born	17.7	18.1	17.9	0.15	0.06
Live born	16.6[a]	17.1[b]	17.0[b]	0.14	0.01
Stillborn	1.0[a] (0.9; 1.1)	0.9[b] (0.8; 1.0)	0.9[b] (0.8; 0.9)	-	0.03
Equalised litter size	13.7	13.7	13.8	0.07	0.06
Piglet mortality, %[1]					
Before litter equalisation	7.5[a] (6.8; 8.1)	7.0[a] (6.4; 7.7)	3.7[b] (3.3; 4.1)	-	< 0.001
Equalisation to d 4	7.6[a] (7.0; 8.3)	6.7[b] (6.1; 7.4)	5.6[c] (5.1; 6.2)	-	< 0.001
D 4 to weaning[2]	5.6[a] (5.0; 6.2)	6.9[b] (6.0; 7.4)	6.6[b] (5.9; 7.4)	-	0.01

[a,b,c] Values with different superscripts differ significantly, $P < 0.05$.

[1]Calculated as percent of live born before litter equalisation and percent of equalised litter size after litter equalisation.

[2]Results from sows that were weaned at 4 wk (LL: n=552, LC: n=492, CC: n=416).

Table 3. Percentage of low mortality sows when sows had been loose housed or confined for the first 4 d of lactation according to 2 different strategies of confinement. Values are presents as estimates and 95% CI.

	Loose-Loose (LL)	Loose-Confined (LC)	Confined-Confined (CC)	*P*-value
	682	668	658	
Low mortality sows, %[1]				
Before litter equalisation	66.0[a] (61.8; 70.0)	67.3[a] (63.1; 71.2)	84.9[b] (81.7; 87.7)	< 0.001
After litter equalisation to d 4	70.1[a] (65.6; 74.1)	73.8[a] (69.5; 77.8)	79.3[b] (75.3; 82.8)	0.002

[a,b] Values with different superscripts differ significantly, $P < 0.05$.

[1]Low mortality sows = sows with 0 to 1 dead piglets in the studied period of time.

Table 4. Effects of sow parity on reproduction and piglet mortality. Values are presented as estimates ± SE or back-transformed estimates and 95 % CI.

	Parity 1	Parity 2	Parity 3+	SE	*P*-value
Number of sows	410	744	854		
Litter size, no					
Total born	16.2[a]	18.0[b]	19.4[c]	0.17	< 0.001
Live born	15.5[a]	17.1[b]	18.0[c]	0.16	< 0.001
Stillborn	0.8[a] (0.7; 1.0)	0.8[a] (0.8; 0.9)	1.1[b] (1.0; 1.2)	-	0.001
Equalised litter size	13.9[a]	13.7[b]	13.5[c]	0.08	0.001
Piglet mortality, %[1]					
Before litter Equalisation	6.5 (5.5; 7.5)	5.4 (4.9; 6.0)	5.6 (5.0; 6.4)	-	0.08
Equalisation to d 4	5.3[a] (4.6; 6.1)	6.9[b] (6.2; 7.6)	7.9[c] (7.2; 8.6)	-	< 0.001
D 4 to weaning[2]	6.7 (5.8; 7.8)	5.6 (4.9; 6.3)	6.5 (5.8; 7.3)	-	0.08

[a,b,c] Values with different superscripts differ significantly, $P < 0.05$.

[1]Calculated as percent of live born before litter equalisation and percent of equalised litter size after litter equalisation.

[2]Results from sows that were weaned at 4 wk (parity 1: n=342, parity 2: n=547, parity 3 to 4: n=571).

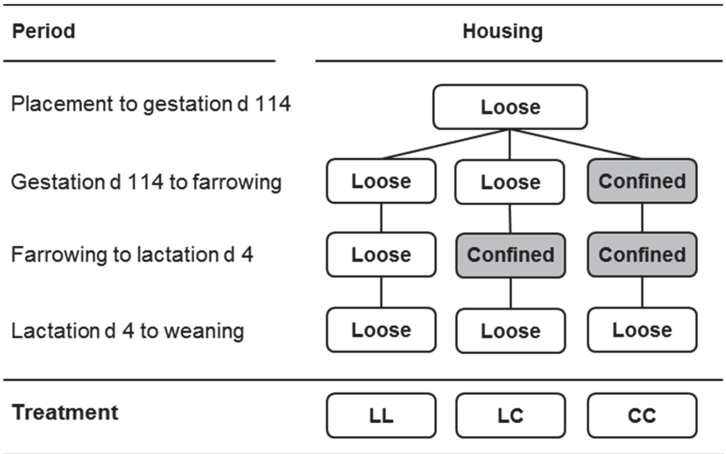

Figure 1. Illustration of the experimental design.

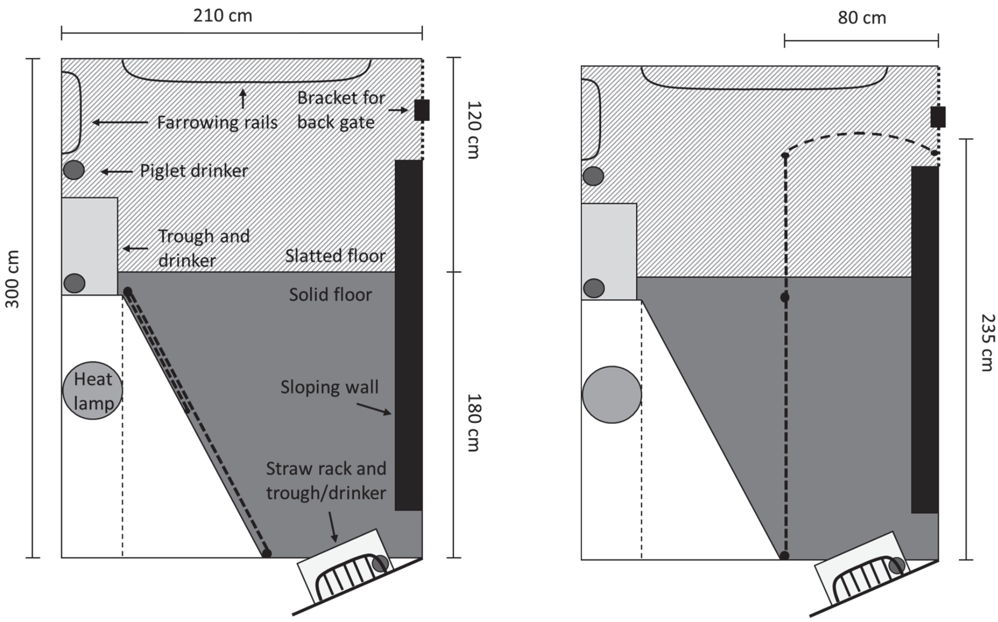

Figure 2. Design of SWAP pen (Sow Welfare And Piglet protection pen) when sow is loose (left) and confined temporarily (right). Grey space = solid concrete floor, diagonal lines = slatted metal floor, white area = covered creep area with heat lamp, black space = sloping wall and dashed outer line = open pen wall/vertical bars.

Paper IV

Confinement of sows in SWAP farrowing pens to day four of lactation influences sow behaviour and saliva cortisol concentration

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Unpublished manuscript.

Confinement of sows in SWAP farrowing pens to day four of lactation influences sow behaviour and saliva cortisol concentrations

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ABSTRACT: The aim of this study was to investigate effects of confinement for four days after farrowing on sow behaviour and saliva cortisol levels. Sows were randomly allocated to three treatments: loose-loose (LL), loose-confined (LC) or confined-confined (CC). Sows in LL were loose housed when they entered the farrowing unit until weaning. Sows in LC were loose housed to the end of farrowing and then confined to day 4 of lactation. Sows in CC were confined from day 114 of gestation to day 4 after farrowing. All sows were loose housed from day 4 to weaning. In general, sow behaviour was characterised by few postural changes and prolonged lateral lying in all treatments, especially on day 1 and 2. Time spent lying lateral was similar across treatments ($P = 0.66$), but CC sows spent more time sitting on day 3 than LC and LL sows ($P \leq 0.001$). Postural changes increased during the day in all treatments but more so in LL than LC and CC ($P = 0.02$) and LL sows had higher frequencies of getting up ($P < 0.05$) and lying down ($P < 0.05$) than LC and CC. The frequency of rolling increased day from day 1 to day 3 in all treatments, but the increase was greater in LL than in LC and CC ($P < 0.001$). Sows stood more during the day than the night but the diurnal pattern differed between the treatments ($P < 0.01$). Sows in LL had more nursings than LC and CC sows on day 1 ($P < 0.001$), and more nursings than CC sows on day 2 ($P = 0.04$) and day 3 ($P = 0.01$). Nursing duration decreased from day 1 to day 2 in all treatments ($P < 0.05$), and was further decreased to day 3 in LL ($P < 0.001$). Sows in LL terminated more nursings than LC and CC sows on day 3 ($P \leq 0.001$). Saliva cortisol concentration was higher in LL sows than LC sows on the day before farrowing and day 1 and day 2 after farrowing ($P < 0.05$) and higher than CC sows on days -1 to 3 ($P < 0.01$) and cortisol was higher in LC sows than CC sows on days 0 and 1 ($P < 0.05$). The results suggest that confinement for four days after farrowing influenced sow behaviour, although only to a minor degree as very little activity occurred. Behavioural differences were not reflected in saliva cortisol concentrations but cortisol response was decreased if sows were confined before farrowing.

Key words: Sow behaviour, lactation, housing, loose sows, temporary confinement

INTRODUCTION

The behavioural patterns of sows before, during and after farrowing are very different -this presents a challenge when it comes to designing a farrowing environment that accommodates the behavioural needs of sows around farrowing and in lactation. During nest building, the activity level of the sows increase significantly, whereas the activity level of sows are generally low and sow behaviour is characterized by prolonged lateral lying in the early days of lactation (Weary et al., 1996; Baxter et al., 2011). Research has documented that sow welfare is impaired in traditional crates (e.g. Damm et al., 2005; Baxter et al., 2012), however, due to a risk of increased piglet mortality, crates are still the most widespread accommodation for farrowing and lactating sows. For an alternative system to be commercially viable, it should not only consider the needs of the sow, but also the needs of the piglets and the producer (Baxter et al., 2011). In an evaluation of alternative systems Baxter et al. (2012) identified designed pens as an alternative to conventional crates. Designed pens are pens with separate lying and dunging areas, features to support the sows' lying down movements and protection features for the piglets (Baxter et al., 2012). In a study of piglet mortality in a designed pen – the FF-pen (Freedom Farrowing pen) – the results showed that there was a large degree of variability in piglet mortality (Hales et al., 2014). The majority of preweaning mortality occurs in the first few days of lactation (Marchant et al., 2001) and previous studies have shown that confinement for 4-7 days after farrowing can reduce piglet mortality compared to loose housed systems (Moustsen et al., 2013). The SWAP-pen (Sow Welfare And Piglet protection pen) was developed as a modification of the FF-pen, where the front of the creep served as a swing-side that could be used to confine the loose housed sows for a short period of time when the piglets seem to need additional protection from the sow. The principle behind the pen was to satisfy the requirements for a loose housed sow during farrowing and lactation but to improve piglet survival in the first days of lactation. Confining the sows prevents them from performing dangerous behaviour such as fast lying down movements and rolling (Weary et al., 1996; Damm et al., 2005; Danholt et al., 2011) hence the risk of crushing should be reduced. Considering that sows are quite inactive in the early days of lactation, the physical restriction that confinement imposes on the sow in this period may not be as detrimental for sow welfare as it may be in other more active periods, such as nest building. Confining sows for a short period of time is therefore expected to have lower impact on sow behaviour and physiology than if sows are confined for longer periods of time, as when they are when confined in crates for the entire lactation period (Cronin et al., 1991). The objective of this study was to establish if sow behaviour and saliva cortisol concentrations were affected by confinement in SWAP pens in first four days of lactation compared to sows that were loose housed. We tested the hypothesis that confinement of sows for the first four days of lactation did not affect sow behaviour or saliva cortisol levels.

MATERIALS AND METHODS

The study was conducted in a Danish 1,250 sow piggery (Krannestrup, Mejlby, Denmark) with Danish Landrace x Danish Yorkshire sows farrowing in weekly batches. All procedures involving animals was conducted in accordance with the guidelines of the Danish Ministry of Justice with respect to animal experimentation and care of animals under study.

Experimental design

A total of 144 sows of parity 1 and 2 were randomly allocated to one of three treatments: loose-loose (LL, n = 48), loose-confined (LC, n = 48) or confined-confined (CC, n = 48). Sows in LL were loose housed from entry to the farrowing unit to weaning after 4 weeks of lactation. In LC sows were loose housed from entry to completion of farrowing (birth of placenta). When farrowing was completed sows were confined to day 4 of lactation. In CC sows were loose housed at entry and confined from day 114 of gestation until day 4 after farrowing. Confinement ended on day 4 and sows in LC and CC were loose housed for the rest of lactation. First parity sows were randomly allocated to one of the treatments and were as far as possible, kept in that treatment for the following farrowings.

Of the 144 sows, 60 sows (10 sows of parity 1 and 10 sows of parity 2 in each treatment) were selected as experimental subjects for the behavioural analyses.

Housing

The mating unit was a group housed system with feeding stalls and the gestation unit was a group system with electronic sow feeding. Five days before expected farrowing the sows were moved to individual Sow Welfare And Piglet protection (SWAP) pens (Figure 1) in the farrowing unit. The farrowing unit was an environmentally controlled building, ventilated via diffuse ventilation with supplemental air inlets to a temperature of 18-20 °C. The farrowing unit was made up of five regular sections with 58 pens each, and two buffer sections with 29 pens each. The SWAP pens measured 210 × 300 cm, had 60% solid concrete floor and 40% slatted cast iron floor (>40% void), a trough with a drinker for the sow, a separate drinker for the piglets, and a creep area for the piglets in the corner towards the inspection aisle. The front of the creep consisted of two metal frames, made up of horizontal bars and seven ‘fingers’ at the bottom bars. Detaching the front in one side turned it into a swing-side that served as confinement for the sow with the sloped wall as the other side of the confinement. A back gate was placed in a bracket on the pen side at the dunging area. Opposite the creep entrance, in the sow resting area, there was a sloped wall to protect the piglets and to support the sows’ lying down movements (Damm et al., 2006). The dunging area was fitted with piglet protection rails and one of the pen sides in the dunging area consisted of vertical bars, allowing contact between the pens. On the pen gate there was a straw rack, an additional trough and a drinker for the sow that could be turned on when the sow was confined. The covered creep area for the piglets had an adjustable lid and the creep area could be closed off with a separate plate. To satisfy the thermal needs of the new-born piglets the creep area was heated via floor heating (~42 °C) supplemented with a heat lamp (150 W) in the first four days of lactation. Sawdust was spread in the creep as bedding material. In addition to the floor heat in the creep there was a circuit for floor heat in the sow area that was on for four days and the floor heat in the creep area was on until piglets were weaned.

Animals and management

Gilts (Danish Landrace × Yorkshire) were purchased at approximately six months of age and all animals were artificially inseminated with semen from Duroc boars (Hatting KS, Horsens, Denmark). In the gestation unit sows were fed a diet based on barley, wheat and soybean containing 8.2 MJ potential physiological energy/kg feed (Boisen, 2001) and 5.3 g standardized ileal digestible Lys/kg feed according to Danish recommendations (Tybirk et al., 2014). In the farrowing unit sows were fed a lactation diet based on barley, wheat and soybean meal that contained 8.7 MJ potential physiological energy/kg feed (Boisen, 2001) and 7.5 g standardized ileal digestible Lys/kg feed. Sows were fed 3 times a day (7:30, 12:30 and 15:30). Before farrowing they received a total ration of 3.7 kg feed/day, and this ration was reduced to 2.5 kg feed/day two days before expected farrowing. On day 2 after farrowing, feeding was increased to 3.2 kg feed/day and the following days the ration was increased by 0.5 kg feed/day until day 6. From day 6 onwards, feeding was increased by 0.5 kg feed every 2 days if sows emptied their troughs. Sows in confinement were fed 2 times a day (7:30 and 15:30) according to the same feeding curve, and straw was provided daily to all sows during the 12:30 feeding to ensure all sows had incentives to get up at all feeding times. When the confined sows were no longer in confinement they were fed 3 times a day. After app. 14 days the number of feeding times was increased to 5 times a day (7:30, 10:30, 12:30, 15:30 and 20:30).

Sows were regularly checked for onset of farrowing from 7:00 in the morning to 22:00 in the evening and obstetric aid was provided when the staff deemed it necessary. At the day of birth dry umbilical cords were cut off when piglets were inspected and injected with 0.5 ml antibiotics (Clamoxyl Prolongatum, Orion Pharma Animal Health, Nivaa, Denmark). Litters were equalised when piglets were 12-24 hours old, provided that they had been ensured colostrum. All litters were equalised to 13-14 piglets within treatment and surplus piglets were moved to a nurse sow. When piglets were 3 days old they were tail docked, injected with a mixture of pain relief (0.2 ml per pig, Melovem, Salfarm Denmark, Kolding, Denmark) and iron (Solofer, Vitfoss, Gråsten, Denmark), orally administered Baycox (Bayer A/S, Copenhagen, Denmark) and males were surgically castrated. After 4 weeks, piglets were weaned. Piglets that were traumatized or diseased- or for other reasons deemed unable to survive to weaning- were humanely euthanized.

Behavioural observations

Video cameras (PTZ Security IR-Dome model no. 795JH, PTZ Security, Esbjerg, Denmark) were placed above the sows and recordings commenced on day 113 of gestation until day 5 after farrowing. The video recordings were stored in avi format (3 fps) on a hard drive using Axxon Next software (AxxonSoft, Moscow, Russia) and converted to jpg files (1 fps) in OGG software (Hoo Technologies, Santa Barbara, USA). The jpg files were imported to RADRA (Pig Research Centre, Copenhagen, Denmark) (Oxholm et al., 2014) where the behavioural registrations were conducted. The date and time of last born piglet was recorded and the date of the first time interval after all piglets were born, was denoted day 0. Behavioural observations were conducted on day 1, 2 and 3 after farrowing in the intervals 4:00-6:00, 10:00-12:00, 16:00-18:00, and 22:00-24:00. Sow posture (standing/walking, sitting, ventral lying, lateral lying - back towards sloping wall, lateral lying - back not towards sloping wall) was recorded when sows changed posture. In addition it was recorded whether or not the sow used the sloping wall as support in lying down events. Postural changes were subsequently divided into lying down (lying down from standing), minor lying down (lying down from sitting), getting up (from lying to standing), minor getting up (from lying to sitting and from sitting to standing), rolling (movements between lying ventrally and lying laterally), rolling ventral to lateral, and rolling lateral to ventral for statistical analyses. Recordings of nursing behaviour included start of nursing (50 % of the litter was active at the udder), end of nursing (less than 50 % of the litter was actively suckling a teat) and whether the nursing was terminated by the sow (sow rolled onto the udder or stood up) or by the piglets (piglets left the udder or fell asleep).

Saliva cortisol

Saliva samples were collected at 8:00, 13:00 and 16:00 from day 114 of gestation to day 4 after farrowing. Samples were obtained using a Salivette ® (Sarstedt, Nürnbrecht, Germany) by fastening the cotton roll on a clamp and letting the sow chew on the cotton roll for approximately 30 seconds or until the cotton roll was saturated. The clamp could be fastened on a long stick to avoid entering the pens if sows were out of reach from the aisle. The cotton roll was returned to the Salivette ® container and centrifuged at 1,000 g for 2 minutes within one hour of sampling to extract saliva. A pooled sample for each day containing 100 μL of saliva from each sampling time was collected in an eppendorf tube. In between sampling times, the pooled sample was stored at -2 °C and when the pooled samples were completed they were stored at -20 °C. Concentration of cortisol was determined by assaying duplicate samples in a salivary cortisol enzyme immunoassay kit (Salimetrics Europe, Suffolk, United Kingdom). Applying a 4-parametric non-linear regression curve fit to the absorbance readings of the standard curve yielded a straight line and the concentration of saliva cortisol was determined in nmol/L.

Statistical analyses

Statistical analyses were performed using SAS ver. 9.3 (SAS Institute Inc., Cary, NC, USA) with sow as the experimental unit and statistical significance was accepted at $P<0.05$. Litter results, piglet mortality and time from end of farrowing to first observation was analysed by use of a non-parametric Wilcoxon test to compare treatment means (LL, LC, or CC). The number of total and specific postural changes, time spent in specific postures, number and duration of nursings, inter-nursing interval and number of nursings terminated by the sow were assumed normally distributed and analysed in linear models with treatment (LL, LC, or CC), day (1, 2, or 3), time (4:00-6:00, 10:00-12:00, 16:00-18:00, or 22:00-24:00), parity (parity 1 or parity 2) and the corresponding interaction terms as fixed effects. Sow was included as random term. Saliva cortisol concentrations were log transformed and fitted a linear model with treatment, day (-2, -1, 0, 1, 2, 3, or 4), parity and corresponding interaction terms as fixed effects, cortisol concentration day -2 as covariate and sow as random term.

RESULTS

One of the CC sows suffered from serious illness and was thus excluded from the study. In addition, two CC sows were not confined before farrowing and ended up in the LC treatment instead leaving 48, 50 and 45 sows in LL, LC and CC respectively.

Of the 60 sows selected for behavioural analyses, one sow in LC and one sow in CC were excluded due to quality of the video recordings. Sows in CC (n = 19) were confined on gestation day 113.9 ± 0.05 and were on average confined for 64.9 ± 6.02 hours before farrowing. After farrowing they were confined for 97.3 ± 0.56 hours which left them in confinement for a total of 170.1 ± 5.25 hours. Sows in LC (n = 19) were confined 1.7 ± 0.38 hours after farrowing and stayed in confinement for 94.9 ± 1.43 hours. Time from the end of farrowing to the first observational period was similar across the three treatments (14.0 ± 1.37 hours, P=0.37).

Litter results and piglet mortality

Results on litter characteristics and piglet mortality are presented in Table 1. The sows had an average parity of 1.5 ± 0.07 (P = 0.98). Litter size was 17.3 ± 0.33 (P = 0.83) with an average of 16.7 ± 0.30 (P = 0.73) live born piglets and 0.6 ± 0.11 stillborn piglets per litter (P = 0.59). Some of the sows were used as nurse sows after day 4 and these sows did not wean their piglets after 4 weeks. The sows that did wean their (own) piglets at 4 weeks of age (n = 17, n = 14 and n = 14 in treatment LL, LC and CC, respectively) weaned an average of 11.5 ± 0.25 piglets (P = 0.07).

Postures

Time spent in different postures for sows in LL, LC and CC is presented in Figure 2 and postural changes are presented in Figures 3-5. Time spent lying lateral was similar across treatments (P = 0.66). There was a diurnal pattern that developed over the three days (P < 0.01) where sows spent less time in lateral position during daytime intervals as lactation progressed. Parity 1 sows spent more time lying lateral compared to parity 2 sows (parity 1: 102.4 ± 1.7 min/interval, parity 2: 94.6 ± 1.7 min/interval; P < 0.001). There was no development over the three days in time spent lying laterally with the back on the sloping wall for sows in LC and CC, but sows in LL spent more time lying with the back against the sloping wall on day 1 compared to day 2 and 3 (P < 0.01). Time spent lying laterally with the back not on the sloping wall followed the diurnal pattern with less time spent in this posture during the daytime intervals than the night-time intervals (P < 0.01). Treatment had no influence on the time spent lying ventrally, but sows spent more time in ventral position during the daytime intervals than during the night-time intervals (P < 0.001), and more time was spent in the ventral position on day 2 and 3 compared to day 1 (P < 0.001). Parity 2 sows spent more time lying ventrally than parity 1 sows (parity 1: 14.5 ± 1.42 min/interval, parity 2: 20.4 ± 1.47 min/interval; P<0.01). Time spent sitting did not differ between treatments on day 1 and 2, but sows in CC spent more time sitting on day 3 than sows in LC and LL (P ≤ 0.001). Sitting also followed a diurnal pattern with more sitting during daytime intervals than night-time intervals (P < 0.01). Sows generally spent more time standing during daytime intervals than night-time intervals, but the diurnal pattern was dissimilar in the three treatments (P < 0.01) and differed in the three days (P < 0.01). In addition, parity 2 sows spent more time standing than parity 1 sows in LL (parity 1: 2.7 ± 0.84 min/interval, parity 2: 7.2 ± 0.84 min/interval; P < 0.001) whereas this was not the case in LC (parity 1: 1.6 ± 0.85 min/interval, parity 2: 3.5 ± 0.89 min/interval; P = 0.26) or CC (parity 1: 3.5 ± 0.85 min/interval, parity 2: 3.1 ± 0.89 min/interval; P = 0.76).

There was a diurnal pattern in the number of posture changes, and this pattern differed between treatments (P = 0.02). Postural changes occurred more during the day (10:00-12:00 and 16:00-18:00) compared to the night-time intervals (4:00-6:00 and 22:00-24:00) (P < 0.05) in all treatments, but in LL sows had more postural changes in the 16:00-18:00 interval than in the 10:00-12:00 interval (P < 0.01). The diurnal pattern of posture changes also changed over the three days (P = 0.03). On day 1 sows had more postural changes in the 16:00-18:00 interval compared to the other intervals (P < 0.01), on day 2 and 3 the number of postural changes was increased in both daytime intervals compared to night-time intervals (P < 0.01). Sows in LL had a higher frequency of getting up than sows in LC and CC (LL: 0.7 ± 0.10 no/interval, LC and CC: 0.3 ± 0.10 no/interval; P < 0.05) and a higher frequency of lying down (LL: 0.9 ± 0.12 no/interval, LC and CC: 0.5 ± 0.12; P < 0.05). The frequency of all getting up and lying down movements increased from day 1 to day 3 (P < 0.001) and getting up and lying down happened more frequently in day time intervals than during the night-time intervals, and more so in the 16:00-18:00 interval than the 10:00-12:00 interval (P ≤ 0.01). Treatment had no influence on the frequency of minor getting up (P = 0.20), but the diurnal pattern of minor lying down differed between treatments (P = 0.02). In LL and CC the frequency of minor lying down was increased in the 16:00-18:00 interval compared to the other intervals (P ≤ 0.01). In LC the frequency of minor lying down increased in the 10:00-12:00 compared to the night-time intervals (P < 0.05), and the frequency in the 16:00-18:00 h interval did not differ from any of the other intervals.

The sows used the sloped wall for support when lying down in 27 %, 35 % and 44 % in LL, LC and CC, respectively, and this proportion did not differ between treatments (P = 0.18). However, parity 1 sows used the sloped wall more often when lying down compared to parity 2 sows (parity 1: 46 ± 5.1 %, parity 2: 24 ± 5.1 %; P = 0.001).

The frequency of rolling increased from day 1 to day 3, in all treatments, but the increase was greater in LL than in LC and CC (P < 0.001). In LL rolling frequency increased from 2.1 ± 0.51 no/interval on day 1 to 5.8 ± 0.51 no/interval on day 3 (P < 0.001), in LC the frequency of rolling was 1.6 ± 0.51 no/interval on day 1 and 3.3 ± 0.51 no/interval on day 3 (P < 0.001) and rolling frequency in CC was 1.7 ± 0.51 no/interval at day 1and 2.7 ± 0.51 no/interval on day 3 (P = 0.03). In LL and LC the increase was furthermore set off by an increase from day 1 to day 2 (P < 0.001), but this was not the case in CC. More rolling was seen in daytime intervals compared to the night-time intervals (P < 0.05), but sows rolled more in the 22:00-24:00 h interval than in the 4:00-6:00 h interval (P = 0.02). Lastly, parity 1 sows performed more rolling than parity 2 sows (parity 1: 3.4 ± 0.31 no/interval, parity 2: 2.6 ± 0.32 no/interval; P = 0.04). Rolling from ventral to lateral and rolling from lateral to ventral followed increased from day 1 to day 3 in all treatments (P < 0.05) according to the same pattern as the frequency of all rolling. The diurnal pattern of rolling from ventral to lateral differed on the three days (P = 0.03) and so did the diurnal pattern of rolling from lateral to ventral differed for parity 1 and parity 2 sows (P = 0.04).

Nursing bouts

Results on nursing bouts are presented in Table 2. The number of nursing bouts decreased from day 1 to day 2 for sows in LL (P < 0.001) and LC (P < 0.01), but not for sows in CC (P = 0.16). Within days, sows in LL had more nursings than both LC and CC on day 1 (P < 0.001), and more nursings than sows in CC on day 2 (P = 0.04) and day 3 (P = 0.01) as well. In addition, the diurnal pattern of nursing frequency was dissimilar in the three days (P < 0.001). The duration of nursing decreased from day 1 to day 2 in all treatments (P < 0.05), but in LL there was a further decrease from day 2 to day 3 (P < 0.001) whereas this was not the case in LC and CC. The duration of bouts was longer in the 4:00-6:00 interval (4.6 ± 0.15 min) and 10:00-12:00 interval (4.5 ± 0.15 min) than in the 16:00-18:00 interval (4.2 ± 0.15 min) and 22:00-24:00 interval (4.1 ± 0.15 min) (P < 0.001), and duration was longer in parity 1 sows than parity 2 sows (parity 1: 4.6 ± 0.15 min, parity 2: 4.1 ± 0.15; P = 0.02). The interval between nursings were shorter in LL (37.9 ± 1.5 min) compared to CC (44.4 ± 1.5 min) (P < 0.01) but neither of these differed from LC (41.7 ± 1.5 min). Inter-nursing interval was furthermore shorter day 1 compared to day 2 and 3 (P < 0.001). The number of potentially successful nursing bouts followed the same pattern as the total number of nursing bouts with fewer potentially successful bouts on day 2 and 3 compared to day 1 in LL ($P < 0.001$) and LC ($P = 0.01$), but not in CC. The number of potentially successful bouts was also greater in LL than in LC and CC on day 1 ($P < 0.001$) and greater than in CC on day 2 and day 3 ($P < 0.05$). The diurnal pattern of in the number of potentially successful nursings differed over the three days ($P < 0.001$) and parity 1 sows had fewer potentially successful nursings than parity 2 sows (parity 1: 3.0 ± 0.10 min, parity 2: 3.2 ± 0.11; $P = 0.02$). The duration of the potentially successful nursings did not differ between treatments ($P = 0.92$), but decreased from day 1 to day 2 (day 1: 5.1 ± 0.13 min, day 2: 4.4 ± 0.13 min; $P < 0.001$) and further from day 2 to day 3 (day 3: 3.8 ± 0.13 min; $P < 0.001$). Again the duration was longer in the 4:00-6:00 and 10:00-12:00 interval than in the 16:00-18:00 and 22:00-24:00 interval ($P \leq 0.01$) and longer in parity 1 sows than parity 2 sows (parity 1: 4.6 ± 0.14 min, parity 2: 4.2 ± 0.14; $P = 0.02$). The number of nursing terminated by the sow increased from day 1 to day 3 for sows in LL ($P < 0.001$) but this was not the case in LC ($P = 0.08$) and CC ($P = 0.14$). Consequently, sows in LL terminated more nursings than sows in LC ($P < 0.001$) and CC ($P = 0.001$) on day 3.

Saliva cortisol

Saliva cortisol concentration were higher in LL than in LC on days -1, 1 and 2 ($P < 0.05$) and higher than CC on days -1 to 3 ($P < 0.01$) (Figure 6). Sows in LC had higher cortisol concentrations than sows in CC on days 0 and 1 ($P < 0.05$). Parity 2 sows had higher cortisol concentrations on days 0, 1, and 4 ($P \leq 0.01$) compared to sows of parity 1 (Figure 7). Cortisol concentrations increased with increasing concentration day -2 ($P < 0.001$).

DISCUSSION

In general, the results of this study showed that regardless of treatment sow behaviour after farrowing was characterised by low frequency of postural changes (< 12 postural changes in two hours) and a large proportion of the time spent in lateral recumbency (80-120 min in two hours), especially day 1 and 2 after farrowing. Loose housed sows displayed a different behavioural pattern than sows that were confined to day 4 after farrowing, but differences were mainly seen on day 3, indicating that sow behaviour was little affected by confinement in the first days of lactation.

In accordance with Weary et al. (1996), sow movements increased over the first three days after farrowing, regardless of housing. However, Weary et al. (1996) did not find any difference in number of movements between sows in pens and crates whereas results in the current study showed that loose housed sows performed more postural changes than confined sows. This is similar to results from a recent study of sows in pens and crates where penned sows had more postural changes in the first 72 hours after birth of the first piglet (Melisova et al., 2014). Increased number of postural changes has been associated with restlessness and discomfort (Harris and Gonyou, 1998) and the loose housed sows did tend to get up and lie down more often, particularly during the day, compared to the confined sows. However, it should be noted that the average frequency of getting up and lying down were lower than two times per interval in the three observational days.

The increased number of postural changes in the loose housed sows was to a large extent driven by an increased frequency of rolling, particularly on day 3. Weary et al. (1996) found fewer rolls from lateral to ventral position in crates compared to pens, but no difference in rolls from ventral to lateral position. Our results showed that both types of rolling were performed more frequently when sows were loose, indicating that confinement prevented rolling in general. The idea behind the confinement in the SWAP pen was to prevent sows from performing dangerous behaviours and the results suggested that this was achieved. Rolling has been identified as dangerous in relation to piglet crushing, especially rolling from the udder to the side (Weary et al., 1996; Danholt et al., 2011). The loose sows had numerically more dead piglets than confined sows but due to the method of recording sow behaviour it is unknown of piglet deaths were associated with rolling in the current experiment. This study did not aim at comparing piglet mortality between the treatments, and the sample size was not expected to be adequate to detect any differences in piglet mortality. Results on piglet mortality has been investigated and reported by Hales et al. (unpublished).

The increased frequency of rolling in the loose housed sows could also be related to nursing behaviour and the ability of the sows to terminate nursings by rolling to the udder. Contrary to the confined sows, the number of nursings terminated by the sow increased over the three days for the loose housed sows and they terminated more nursings than the confined sows by day 3. According to Thodberg et al. (2002) penned sows terminated more nursings than crated sows on day 10 and penned sows were interpreted as being more in control than crated sows. Others showed that sows in crates terminated a higher number of nursings compared to sows on pens because nursings were more frantic in crates (Pedersen et al., 2011). This study was however, conducted at a later stage of lactation (day 14 and 28), where piglets are bigger and the process of weaning is starting. Confinement might influence nursings differently at this stage compared to the very early stage where the piglets are small and the cyclic pattern of nursing is developing. Thodberg et al. (2002) suggested that the increased control in pens was associated with a faster development of a cyclic nursing pattern. However, the number of nursings and the duration of nursing bouts did not differ between loose housed sows and sows that were confined after farrowing indicating that confinement per se did not affect the development of a cyclic pattern. According to Cronin and Smith (1992), sows in pens had longer bouts of suckling grunts than sows in crates on day 1-3. We found differences in the number of nursings, but not the duration of bouts, between the loose housed sows and the sows that were confined before farrowing. Limiting the available space during nest building can affect maternal behaviour negatively (Jarvis et al., 2004), but the time of confinement (before or after farrowing) did not influence nursing frequency or duration in this study. This is in contrast to Yun et al. (2013), who found longer duration of successful nursing bouts (average of observations on day 3 and 6) if sows were housed in crates compared to pens during nest building. Similar to our study, both crated and penned sows were confined after farrowing, but crated sows had been confined from approximately seven days before farrowing whereas the sows that were confined before farrowing in the current study had been in confinement for approximately three days. In addition, differences might be attributed to the days of observation or the definition of recorded behaviours. Consequently, there are indications that confinement before farrowing affects nursing behaviour although more detailed studies are needed in order to elaborate on these influences of confinement.

As seen in other studies (e.g. Cronin et al., 1994; Danholt et al., 2011), the early days of lactation were associated with prolonged lateral lying regardless of housing system. However, the loose housed sows spent more time standing (up to 12 min in two hours on day 3) during the daytime hours than the confined sows did and the confined sows showed an increase in time spent sitting on day 3, although the duration of sitting was still low (approximately 5 min in two hours). Other behavioural studies have shown that crated sows sat more than penned sows during nest building and in the first 8 hours after birth of the first piglet (Jarvis et al., 1997; Damm et al., 2003; Jarvis et al., 2004). It was suggested that sitting reflected motivational conflicts because sows were motivated to nest build before farrowing and to interact with and investigate the new born piglets, but these behaviours could not be performed in the crate (Jarvis et al., 2004). The increased sitting on day 3 may be associated with the possible restrictions of nursing behaviour, but as increased sitting was only seen in the sows that had been confined before farrowing, the duration of confinement might also play a role. However, there was no indication in the results on saliva cortisol that sows that were confined before farrowing exhibited increased physiological stress on day 3 compared to the other days. The results on saliva cortisol concentrations suggested that saliva cortisol response was decreased in sows that were confined before farrowing and that the response around farrowing overruled any response to environment in the first days of lactation. This is in contrast to Cronin et al. (1991) and Jarvis et al. (2006) who did not detect any difference in between penned and crated sows around farrowing. Oliviero et al. (2008) found that crated sows had higher cortisol levels day 1-5 after farrowing compared with penned sows. One of the major differences between our studies and other studies of HPA activity in penned and crated sows is the time of confinement. Whereas sows in traditional farrowing crates are usually confined from the day they enter the farrowing unit - sows in our study were loose housed at entry and confined two days before expected farrowing. Finally, the results on saliva cortisol suggested that parity 2 sows experienced increased stress around farrowing compared to parity 1 sows. This is possibly related to the fact that parity 1 sows were likely to give birth to smaller litters than parity 2 sows (Hales et al. 2014), and both parity and litter size may have increased duration of farrowing (Herpin et al., 1996; Hales et al., 2015), which could prolong the period of high cortisol levels around farrowing. This effect of parity should however be acknowledged in further research. In this study, only one indicator of sow physiology was used and using multiple indicators would likely improve the understanding of effects of temporary confinement on sow physiology. The differences between the results on saliva cortisol concentration and the behavioural patterns did however show that it is useful to include both behavioural and physiological indicators to understand how sows were affected by temporary confinement.

CONCLUSION

Confinement of sows for four days after farrowing did influence sow behaviour in that the frequency of lying down and rolling was reduced and nursing behaviour developed somewhat different. However, due to the low levels of activity the influence of confinement seemed minor. The behavioural differences were not reflected in saliva cortisol concentrations however this could have been influenced by a dampened cortisol response around farrowing in the sows that were confined before farrowing.

Acknowledgement

Funding for this project was provided by the Danish Pig Levy Foundation and The Danish Rural Development Program 2007-2013/The European Agricultural Fund for Rural Development. We would like to thank everyone working at Krannestrup for their collaboration and participation in the study. We would also like to acknowledge Alexander Grahofer, Camilla

Højgaard, Mogens Jakobsen, Erik Bach and Jens Ove Hansen, for practical assistance and help with data collection.

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Table 1. Reproductive performance and results on piglet mortality for sows that were loose housed and sows that had been confined to day 4 of lactation according to two different strategies of confinement. Values are presented as means ± SE.

	Loose-Loose (LL)	Loose-Confined (LC)	Confined-Confined (CC)	SE	*P*-values
Sows, n	20	19	19		
Total born, no	17.3	17.2	17.5	0.57	0.83
Live born, no	16.8	16.5	17.0	0.52	0.73
Stillborn, no	0.5	0.7	0.5	0.18	0.59
Equalised litter size, no	14.1	14.0	13.8	0.16	0.64
Live born mortality before equalisation, no	1.0	0.4	0.5	0.23	0.09
Mortality from equalisation to day 4, no	0.4	0.5	0.6	0.16	0.79

Table 2. Nursing behaviour day 1 to day 3 of lactation for loose housed sows (LL, n = 20), sows that were confined from the end of farrowing to day 4 after farrowing (LC, n = 19) and sows that were confined from gestation day 114 to day 4 after farrowing (CC, n = 19). Values are presented as estimates ± SE.

					P-values		
	LL	LC	CC	SE	Treatment	Day	Treatment × Day
Nursing bouts, no/interval				0.19	< 0.001	< 0.001	0.01
Day 1	$4.5^{a,x}$	$3.4^{b,x}$	3.0^{b}				
Day 2	$3.3^{a,y}$	$2.9^{a,b,y}$	2.7^{b}				
Day 3	$3.3^{a,y}$	$2.8^{a,b,y}$	2.6^{b}				
Nursing bout duration, min				0.24	0.91	< 0.001	0.03
Day 1	5.3^{x}	5.1^{x}	4.7^{x}				
Day 2	4.3^{y}	4.1^{y}	4.2^{y}				
Day 3	3.6^{z}	3.8^{y}	3.9^{y}				
Inter-nursing-interval, min				2.02	0.01	< 0.001	0.85
Day 1	32.5	37.7	40.3				
Day 2	41.5	43.4	46.2				
Day 3	39.7	43.8	46.8				
Successful nursing bouts, no/interval				0.18	< 0.001	< 0.001	< 0.001
Day 1	$4.6^{a,x}$	$3.3^{b,x}$	2.9^{b}				
Day 2	$3.3^{a,y}$	$2.8^{a,b,y}$	2.6^{b}				
Day 3	$3.1^{a,y}$	$2.8^{a,b,y}$	2.6^{b}				
Successful nursing bout duration, min				0.23	0.92	< 0.001	0.07
Day 1	5.4	5.2	4.8				
Day 2	4.3	4.3	4.4				
Day 3	3.7	3.8	3.9				
Nursings terminated by the sow, no				0.16	0.32	< 0.001	<0.001
Day 1	0.3^{x}	0.6	0.7				
Day 2	1.1^{y}	0.8	0.8				
Day 3	$1.6^{a,z}$	0.9^{b}	0.9^{b}				

^{a,b} Values within day (rows) with different superscripts differ significantly, P < 0.05.

^{x,y,z} Values within treatment (columns) with different superscripts differ significantly, P < 0.05.

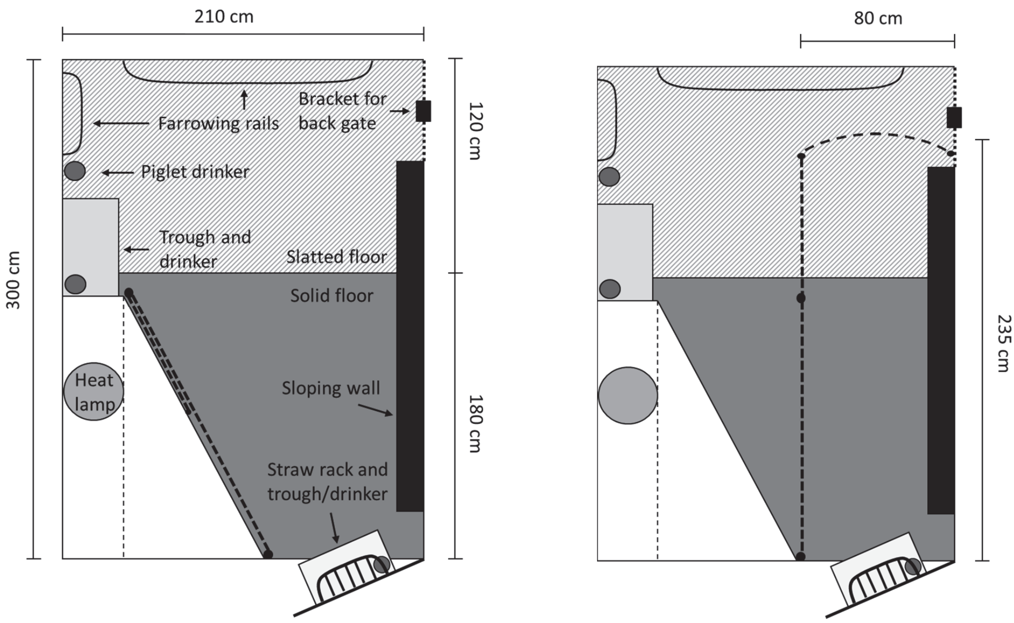

Figure 1. Illustration of the SWAP farrowing pen (Sow Welfare And Piglet protection) when sow is loose (left) and confined temporarily (right). Grey space = solid concrete floor, diagonal lines = slatted metal floor, white area = covered creep area with heat lamp, black space = sloping wall and dashed outer line = open pen wall/vertical bars.

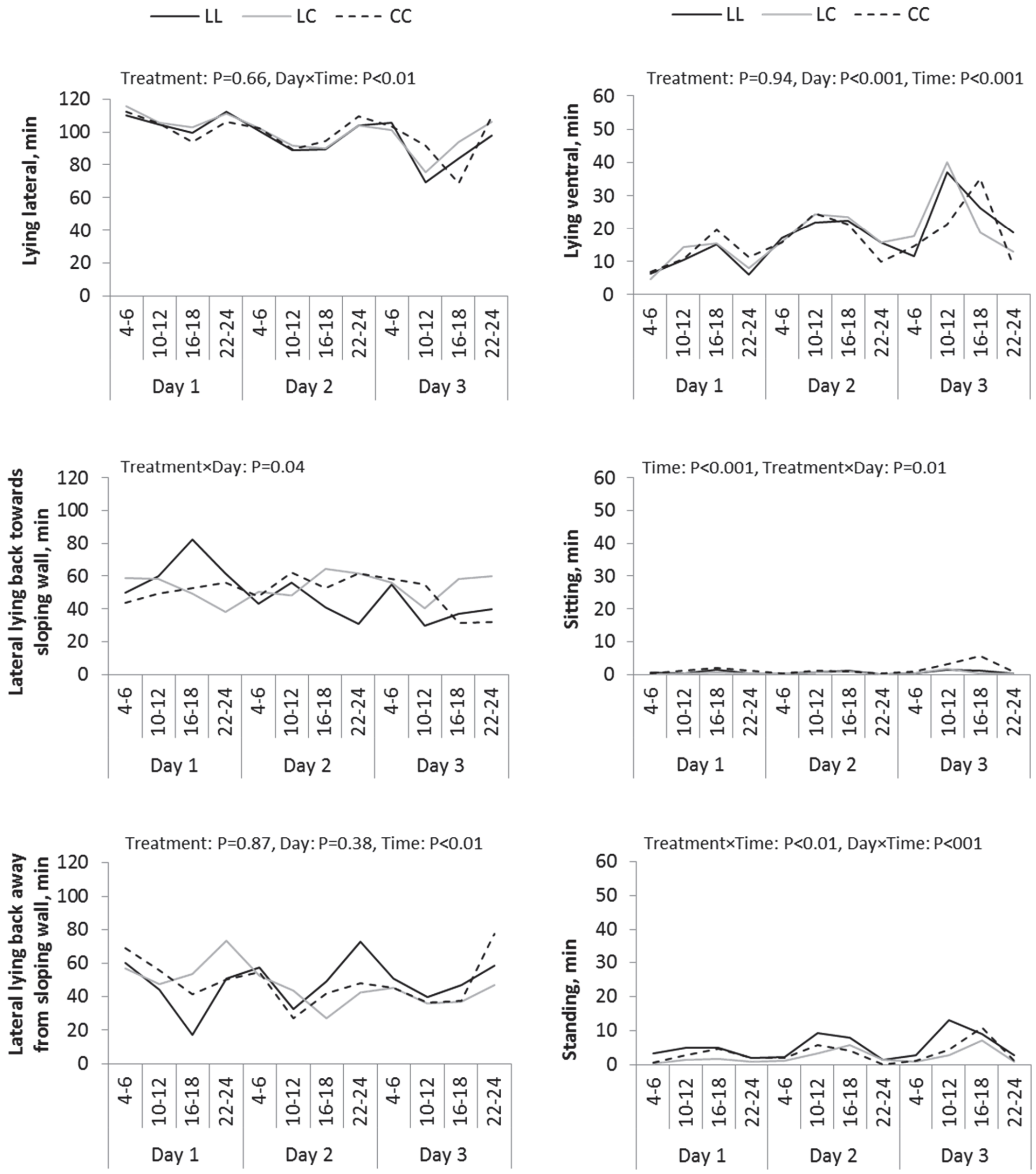

Figure 2. Duration of postures from day 1 to day 3 for loose housed sows (LL, n = 20), sows that were confined from the end of farrowing to day 4 after farrowing (LC, n = 19) and sows that were confined from gestation day 114 to day 4 after farrowing (CC, n = 19).

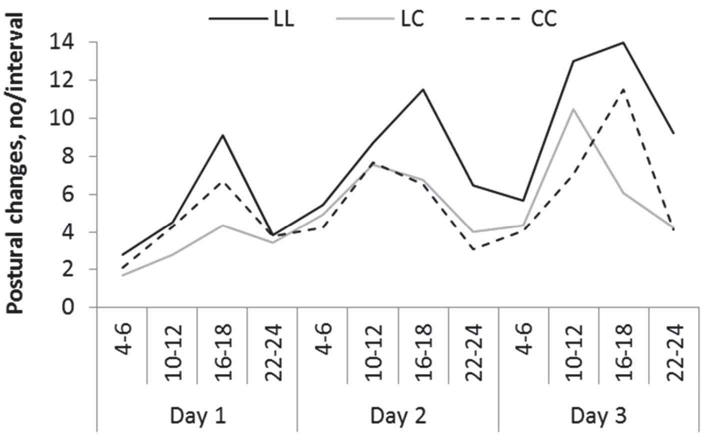

Figure 3. Postural changes from day 1 to day 3 for loose housed sows (LL, n = 20), sows that were confined from the end of farrowing to day 4 after farrowing (LC, n = 19) and sows that were confined from gestation day 114 to day 4 after farrowing (CC, n = 19). P-values: Treatment × Time: P=0.02, Day × Time: P=0.03.

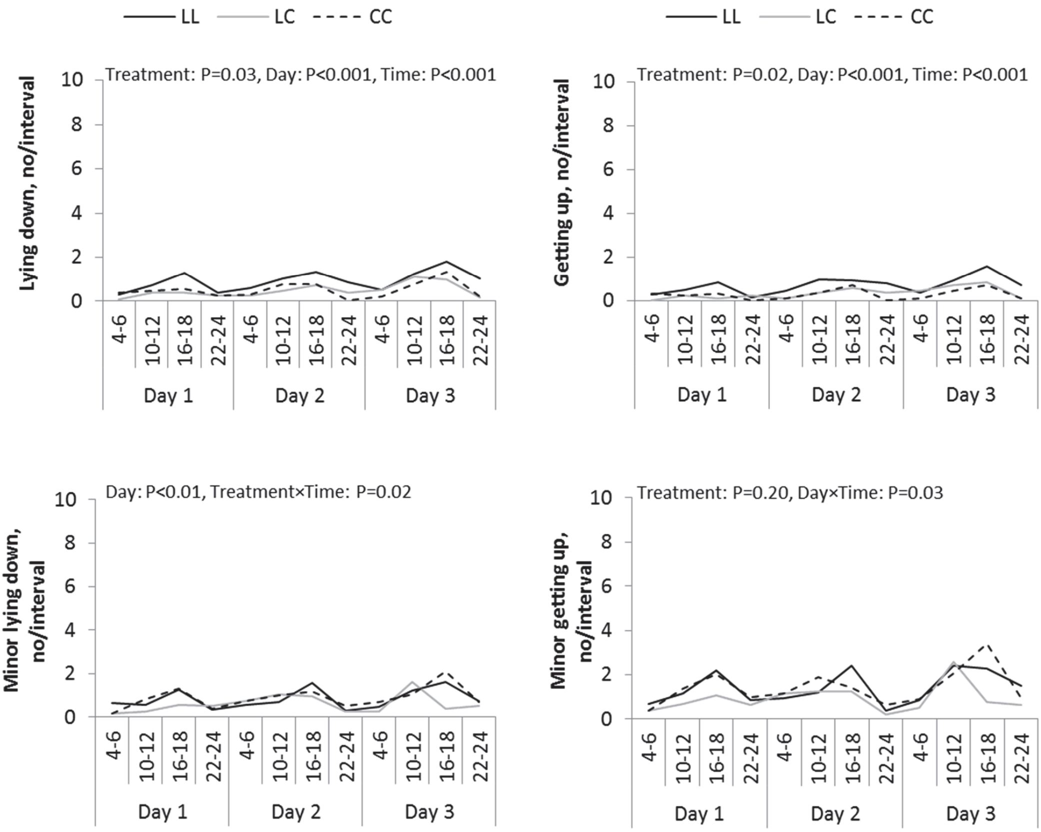

Figure 4. Frequencies of lying down, minor lying down, getting up, and minor getting up from day 1 to day 3 for loose housed sows (LL, n = 20), sows that were confined from the end of farrowing to day 4 after farrowing (LC, n = 19) and sows that were confined from gestation day 114 to day 4 after farrowing (CC, n = 19).

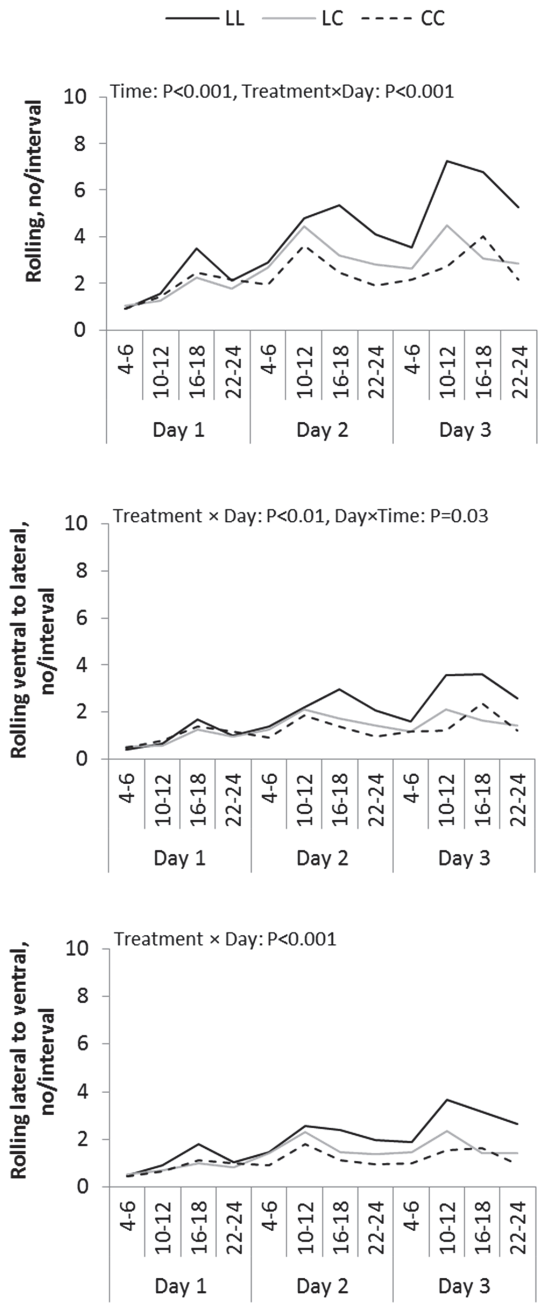

Figure 5. Frequencies of rolling from day 1 to day 3 for loose housed sows (LL, n = 20), sows that were confined from the end of farrowing to day 4 after farrowing (LC, n = 19) and sows that were confined from gestation day 114 to day 4 after farrowing (CC, n = 19).

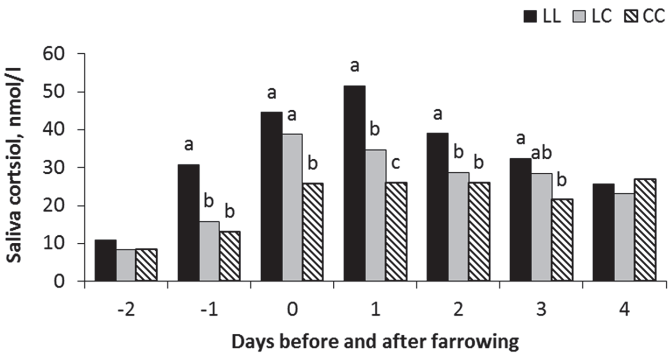

Figure 6. Saliva cortisol concentration from two days before farrowing to day 4 of lactation for loose housed sows (LL, n = 48), sows that were confined from the end of farrowing to day 4 after farrowing (LC, n = 50) and sows that were confined from gestation day 114 to day 4 after farrowing (CC, n = 45). Treatment × Day: P < 0.001. Columns within day with different superscripts differ significantly, P < 0.05.

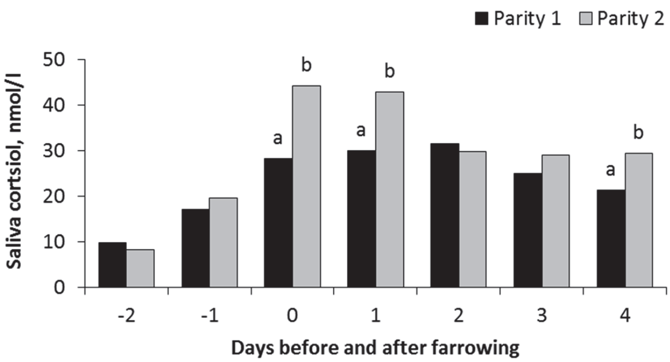

Figure 7. Saliva cortisol concentration from two days before farrowing to day 4 of lactation for sows of parity 1(n = 81) and parity 2 (n = 62). Parity × Day: P < 0.001. Columns within day with different superscripts differ significantly, P < 0.05.

DEPARTMENT OF LARGE ANIMAL SCIENCES
FACULTY OF HEALTH AND MEDICAL SCIENCES
PHD THESIS 2015 · ISBN 978-87-7611-871-6

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Loose housing or temporary confinement of sows in designed farrowing pens