RESEARCHREPORT

ANIMAL WELFARE

Title: Systematic Literature Review and Needs Assessment of Housing Systems for Lactating sows and Their Litters – **NPB #11-182** **revised**

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INDUSTRY SUMMARY

The farrowing crate is one of several common animal husbandry practices facing increased public scrutiny across the globe. Like a gestation stall, similar welfare concerns are expressed about practices that restrict the movements of animals and questions arise about alternatives to the farrowing crate. Unlike the gestation stall, the needs of the piglets also need to be considered when assessing welfare during this phase of production. The goal of this report is to review the scientific literature relevant to North American swine production on both sow and piglet welfare in different lactational housing systems. A systematic review process was adopted in an effort to provide an objective and transparent assessment of peer-reviewed work on lactational housing system for modern, commercial breeds of sows. We examined findings on the behavior, physiology and performance of both sows and piglets in 4 different types of housing systems: farrowing crate, hinged crate, individual pen, and group pen. Despite a relative scarcity of information on this topic, the following important themes emerged from our review. Farrowing crates likely provide welfare challenges to sows during the nesting and lactation phase of this stage of production. Resulting aberrant sow behaviors such as restlessness during farrowing and unresponsiveness to piglet vocalizations can contribute to piglet mortality observed in crates. However, the emerging consensus suggests that farrowing crates can provide a welfare advantage to the piglet by limiting additional mortality, especially during early lactation. Alternative farrowing systems can, but do not always, have comparable piglet performance, perhaps related to the role of humans in the management of these systems. A secondary goal of this review was to detail knowledge gaps in the literature. Several possibly fruitful areas of future research are described that promise to contribute to the design of a lactational housing system that best optimizes the needs of the sow, the piglet, and the farmer.

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SCIENTIFIC ABSTRACT

The farrowing crate is one of several common animal husbandry practices facing increased public scrutiny across the globe. Like a gestation stall, people are expressing welfare concerns about practices that restrict the movements of animals and are asking for alternative housing regimes. Unlike the gestation stall, the needs of the piglets also need to be considered when assessing welfare during this phase of production. The goal of this report is to review the scientific literature relevant to North American swine production on both sow and piglet welfare in different lactational housing systems. A systematic review process was adopted in an effort to achieve quantitative data synthesis of related research findings through inverse variance weighting meta-analysis. Two study subpopulations, sows and piglets, with in the population of sows and litters of modern, commercial breeds were identified, as well as 4 housing interventions (farrowing crate, hinged crate, individual pen, and group pen) and a variety of welfare outcomes that could be grouped in to 3 general categories (behavior, physiology, and performance). Given the paucity of relevant peer-reviewed reports on lactational housing, meta-analysis was abandoned and qualitative data synthesis pursued. Despite the scarcity of information on this

topic, the following important themes emerged from our review. Farrowing crates likely provide welfare challenges to sows during the nesting and lactation phase of this stage of production. Resulting aberrant sow behaviors such as restlessness during farrowing and unresponsiveness to piglet vocalizations can contribute to piglet mortality observed in crates. However, the emerging consensus suggests that farrowing crates can provide a welfare advantage to the piglet by limiting additional mortality, especially during early lactation. Alternative farrowing systems can, but do not always, have comparable piglet performance, perhaps related to the role of humans in the management of these systems. A secondary goal of this review was to detail knowledge gaps in the literature. Several possibly fruitful areas of future research are described that promise to contribute to the design of a lactational housing system that best optimizes the needs of the sow, the piglet, and the farmer.

INTRODUCTION

Common North American swine husbandry practices utilize stalls, also called crates, during both the gestational and lactational phases of a sow's production cycle. In recent years, sow gestational housing has been closely scrutinized. This is leading to a re-evaluation of production methods and a movement away from gestational stalls toward group housing. The criticism against gestation stalls has centered on their limiting sow movement and natural behavioral expression despite offering the sow protection from physical aggression and the ability for care takers to offer improved individual animal care. Sows housed in farrowing crates face the same advantages and disadvantages of sows in gestation stalls. However, the situation with farrowing crates is more complicated by the presence of piglets. Farrowing crates also aim to improve piglet survivability by protecting them from crushing deaths. Thus, piglet welfare and productivity also must be considered when assessing lactational housing systems.

Farrowing crates are the most common form of sow and litter housing in the United States (US), European Union, and the United Kingdom (Johnson and Marchant-Forde, 2009; Pedersen et al., 2013). In the US, the farrowing crate has not yet received as much attention as the gestation stall. However because of perceived welfare shortcomings, Sweden, Norway, and Switzerland have banned their use (Pedersen et al., 2013) and that critical gaze is spreading across Europe and eventually will fall on their use in the US. Recent reviews on lactational housing systems by European authors (Baxter et al., 201; Baxter et al., 2012; Pedersen et al.,2013) have focused on translating existing knowledge about pen based farrowing systems into on-farm recommendations given their immediate need for alternatives to the conventional farrowing crate.

OBJECTIVES

In North America, we are not faced with the same degree of urgency to address concerns about farrowing crates. As such, the objective of this review is two- fold. First is to summarize findings from the scientific literature that compare farrowing crates with alternative methods of housing sows and their litters during lactation. Second is to identify gaps in this body of knowledge that would benefit from further research. Our overarching goal is to lay the foundation necessary to create the new knowledge required to design alternative farrowing systems that best optimize the needs of the sow, the piglet, and the farmer.

METHODS

We employed the general principles of a systematic review process in the generation of this document. Much effort has been devoted in the last decade to standardizing the review of human medical studies (for review see Grant and Booth, 2009; Cooper et al., 2009). We were informed by the systematic review guidelines recently published by O'Connor and Sargeant (2014) for animal health and welfare literature.

I. Study Eligibility

The first step in a systematic review process is to identify the review question(s). Specific objective criteria must be identified to define the components of the review question. Our review question was developed according to the population, intervention, comparator, outcome, and study design (PICOS) format (O'Connor and Sargeant, 2014). The goal of this approach is to be both objective and transparent in the selection of the relevant body of literature considered. Here are the criteria we elected for our review questions.

Population. The study population (P) was sows and litters of modern, commercial breeds with sows and piglets being the 2 sub-populations. To specify modern genetics, only research studies published after 1993 were considered. Similarly, studies using miniature and indigenous pig breeds were excluded as they are not commercial breeds of pig.

Intervention. Housing lactating sows and their pigs in indoor, alternative farrowing systems was considered the intervention (I). Alternative housing types were aggregated into 3 categories: individual pen, group pen, and hinged crate. Individual pens housed a single sow and her litter in a space sufficient for the sow to turn-around. Round and ellipsoid crates (Lou and Hurnik, 1994, 1998; Blackshaw, 1997) were included with the individual pens as the sow could turn around in them. A group pen system housed ≥ 2 sows and their litters in a manner such that the sows could interact with other sows. These systems may have included individual crates or pens for the sows along with the communal space and piglets may or may not have interacted with other litters. A hinged crate system included a crate that fixed the sow in position at certain time periods, but was opened up at other times allowing the sow sufficient space to turn-around. Aggregating the systems into only 3 categories potentially obscured some housing differences within each category, but was required in the pursuit of quantitative data synthesis.

Comparator. Conventional farrowing crate housing, in which space was insufficient for the sow to turn-around, was chosen as the comparator (C). Only studies that incorporated both an intervention and the comparator in their design were included in the initial analysis. This insured that we had a standard reference for comparison of the outcomes of the intervention and helped to account for any study variation in management, nutrition, genetics, etc.

Outcomes. Several different outcomes (O) that were potentially indicative of the animals' welfare were selected (Table 1). These were divided into behavior, physiology, or performance groupings and classified by animal subpopulation. These were further subdivided by time period: nesting (before the first pig was born), farrowing and neonatal (first pig born to 3 d of age), lactation (4 d of age to weaning), and post-weaning (weaning to slaughter) phases. This resulted in a minimum of 17 possible outcome categories as not every animal subpopulation or class of outcome were relevant to each of the 4 time periods considered (Table 2). Often multiple types of measures or assays were available within a given category (e.g. cortisol, prolactin, etc.) and highlight the challenges of applying a systematic review approach to a broadly defined literature base such as lactational housing. In essence, we resulted in a portfolio of review questions. Examples of review questions include "Do cortisol concentrations differ between sows housed in individual pens and farrowing crates during the nesting phase?" and "Does the number of piglets that die differ between group pens and farrowing crates during the neonatal period?"

Study design. The studies (S) considered were randomized or non-randomized controlled trials published in a peer-reviewed English language journal after 1993. Typically, the gold standard study design for this type of review process would be a double-blinded, randomized controlled trial that is often used in human medicine. Given that the intervention identified in our review questions was housing type, it was largely impossible to find any true blinded trials. Also we were rarely able to find randomized studies as treatment assignment was typical driven by availability of housing facilities.

II. Database search and study selection

The initial literature search was conducted in November 2013 and was updated monthly until September 2014. The 6 databases searched were Agricola (USDA, 1970 to present), BIOSIS Previews (Thompson Reuters, 1926 to present), CAB abstracts (CAB International, 1910 to present), PubMed (NCBI, 1950 to present), Web of Science (Thompson Reuters, 1898 to present), and Scopus (1823 to present). Several important keywords included were: farrow, housing, lactation, nursing, sow, and piglet (see Appendix A for complete search terms).

The search identified 5605 abstracts. After removing duplicates (EndNote X6, Thompson Reuters, NYC, NY), the remaining 3525 abstracts were screened for relevance (see Appendix B for relevance tool) to assess that the study included an appropriate population, intervention, and comparator. We subsequently revised our criteria that the article be published after 1993 to better reflect the timing of the change in sow genetics in the US and added the additional criterion that the intervention be an indoor housing type. Sixty-one articles remained and an additional 4 were added as they were published (Table 3).

III. Data extraction and tabulation

Data were extracted from the text, tables, and figures (ImageJ, National Institutes of Health, Bethesda, MD) of the articles. Extracted data included the authors' names, year of publication, country where the research was conducted, phase of production, day and time the data were collected, housing type, outcome mean and units of measurement, standard deviation or error, and sample size. If an outcome was reported as "not different" between the housing types and the only mean provided was averaged to include all the treatments, that mean and its variation were entered for all the treatments in the study. We did this to minimize the risks associated with positive result reporting biases. Missing data were noted. Given our focus on peer-review published data no authors were contacted for additional information and no additional outcomes were calculated with the provided data.

IV. Data synthesis

One goal of the systematic review process is to provide some type of quantitative synthesis of the data extracted from the relevant body of literature. Meta-analysis is a typical solution to quantitative synthesis as it offers a statistical technique for combining the findings from independent studies (Stroup et al., 2000). Inverse variance weighting of study outcomes is often used in meta-analysis to provide a precise estimate of a treatment effect such as housing type. With this approach, results from studies with less experimental variation and or larger sample sizes are more heavily weighted. We employed the "meta" package in R (http://cran.r-project.org/) to carry out meta-analysis using the following commands "metacon," "metainf," "forest" and "funnel." For instance, we compared cortisol concentrations between sows housed in pens versus crates ranging from 48 h prepartum to 6 h postpartum. The forest plot (Fig. 1) depicts that consistently and reproducibly all 15 studies resulted lower cortisol concentrations among sows housed in individual pens than farrowing crates. A mean difference of -13.2 ng/mL cortisol concentration ($P < 0.0001$) is estimated for sows housed in individual pens (Table 4). This example highlights the powerful approach that meta-analysis provides for quantitative data synthesis using multiple studies.

Unfortunately, as we applied this methodology to other data sets generated by our review process, several known limitations of meta-analysis in estimating treatment effects were observed (Flather et al., 1997). A comparison of prolactin concentrations between sows housed in individual pens or farrowing crates that used 12 studies found no significant difference (P = 0.9045; Fig. 2). However, evidence of significant heterogeneity in the data (I^2 = 56.7%; P =0.0079; Table 4) questioned the usefulness of this comparison. Heterogeneity is a measure of unexplained variation between studies and may result from factors other than the one of interest contributing to study outcomes (Higgins and Thompson, 2002). Furthermore, a comparison of the total number of piglets born alive between individual pens and farrowing crates also yielded no difference (P =0.7859; Fig. 3). In this example, one study, Weber et al. (2007), dominates the analysis contributing to 99% of the estimate of the difference between crates and pens (Table 4). A similar problem was identified when generating estimates of pre-weaning mortality between lactational housing systems (data not shown).

The meta-analysis repeatedly failed due to the paucity of appropriate studies describing lactational housing systems. The inverse variance weighting paradigm used in the meta-analysis heavily favors studies with large numbers of observations and thus our approach was compromised by having a single study in the analyses that was an order of magnitude larger than the others. There also were several studies that compared productivity between different types of farrowing systems (Moustsen et al., 2013; Hales et al., 2014; Melišová et al., 2014) that we were unable to include in the meta-analysis. The papers reported a pooled, rather than an individual, error term for the different treatment groups. Given our inability to systematically apply meta-analysis to all our review questions, we were forced to abandon quantitative data synthesis. This unfortunately has been reported to be a frequent outcome when systematic review methodology is applied to questions related to animal health and welfare (O'Connor and Sargent, 2014).

V. Expert Panel

An expert panel was assembled for a 3 day workshop in January 2014. See Appendix C for the participant list. The major goal of the panel was to identify and prioritize possible study outcomes. The group also helped shape the criteria for paper inclusions in the review process. In the absence of a quantitative data synthesis, several members of the expert panel were invited to provide a qualitative synthesis of research findings relevant to our different review questions with an emphasis on identifying knowledge gaps. These co-authors have in some cases included additional references in their summaries. The resulting lactational housing literature review and knowledge gap analysis is described below.

RESULTS AND DISCUSSION

I. Overview

The assessment of overall welfare within farrowing systems presents a unique challenge for pork producers, veterinarians, and animal scientists. Welfare assessments within all other phases of swine production involve pigs at a single stage of their productive life. Within the farrowing environment, the sow and her piglets are at two very different stages of their lives and have differing requirements in regards to their thermal, social, and physical environments (Marchant-Forde, 2011).

In addition to physical needs, sows and piglets also differ in their behavioral needs during certain time periods (Baxter et al., 2011). Under natural conditions, there are a complex series of behaviors performed in which sows and piglets experience various degrees of isolation followed by community reintegration and living. These behaviors can be divided into six distinct phases: (i) isolation and nest site seeking, (ii) nest building, (iii) farrowing, (iv) nest occupation, (v) social integration, and (vi) weaning (Jensen, 1988).

For the purposes of this review, isolation and nest site seeking and nest building are combined in the nesting phase (before the birth of the first pig) and farrowing and initial nest occupation are included in the farrowing and neonatal phase (first pig to d 3 postpartum), but all 6 phases are discussed separately if the data is available. Later nest occupation and social integration are included in the lactation phase (d 4 postpartum to weaning). As neonatal piglets are at a greater mortality risk than older piglets, nest occupation is divided into a neonatal and later lactational period. Weaning, which in production is usually an abrupt event rather than an extended phase, separates the lactation and post-weaning phases.

There are a variety of housing options available for the farrowing and lactating sow and her litter. These range from indoor housing in conventional crates to outdoor housing in paddocks. Additionally, sows can be housed individually through all parturition phases, housed in groups throughout all phases, or initially housed individually and group housed later in lactation. However, seen in the context of natural behavior, it is essentially impossible to design a commercial lactational housing system that does not conflict with at least one aspect of natural farrowing and lactational behavior. Therefore, every lactational housing system in commercial use or experimental development will incur some degree of sow and piglet behavioral compromise.

The expression of nesting behavior may be the most important behavioral indicator of sow welfare as nesting is a highly motivated behavior (Arey al., 1991). Its continuation after birth and other sow behaviors such as postural changes also have piglet welfare implications. For piglets, successful nursing is likely the most important behavioral welfare indicator as colostrum intake influences subsequent weight and survivability (Devillers et al., 2011). Studies that used physiological indicators of sow welfare have largely focused on cortisol, as a measure of stress, and reproductive hormones which are known to be negatively impacted by activation of the stress response. However, very few studies have used physiological indicators to assess piglet welfare in alternative lactational housing. Key performance indicators measured in alternative lactational systems are related to piglet survival rate including: total number of piglets born, number born alive, number born dead, percentage live-born mortality (i.e. piglets that are born alive but die before weaning), percentage total mortality (i.e. live-born deaths pre-weaning and born dead), and numbers weaned. As most pre-weaning piglet mortality is attributable to being crushed under the sow (Marchant et al., 2000; Edwards, 2002; Kilbride et al., 2012), it is both a production and welfare issue. Additional data that are sometimes, but rarely recorded consistently include sow condition (weight, body condition score, and back fat thickness) before farrowing and at weaning and piglet weight gain.

The following discussion is structured by time phase: nesting, farrowing and neonatal, lactation, and post-weaning. With the exception of nesting which includes the sow only, within each phase, the sow subpopulation is considered prior to the piglet subpopulation. And within each subpopulation the behavior, physiology, and performance outcome categories are considered in that order. Each time phase concludes with an examination of the current gaps in the research literature. Because of the research gaps, some categories (e.g. post-weaning sow physiology) are absent from this overall structure (Table 2). A short discussion of the industry relevance concludes the review.

II. Nesting phase (before the first pig is born)

II A. Sow Behavior

II A 1. Isolation and nest-site seeking phase (48 to 24 h prepartum). Given the opportunity, sows will leave their social group and seek isolation 48 to24 h prior to the birth of the first piglet. Sows investigate many potential nesting sites before finally choosing one that typically provides a degree of both vertical and horizontal protection. Sows often choose sites outside their usual ‘‘home range.’’ The importance of this process may be gauged by the long distances, up to several kilometers (Jensen, 1986), that sows are willing to walk to find an appropriate site.

II A 1 a. Substrate directed and redirected behavior. Sows in get-away pens, individual pens that allow the sow to separate from the piglets, commenced prepartum rooting behaviors (primiparous: -41.3 h, biparous: -35.6 h) before sows in farrowing crates (primiparous: -32.5 h, biparous: -27.4 h; Thodberg et al., 2002a). However the treatments also differed in available substrate; sows in the get-away pens received 2 kg of straw daily, whereas those in the crates received only small amounts of straw twice daily. When no substrates were provided, sows in small pens (4.4 m^2; 33.7 min /d) rooted the floor longer than sows in farrowing crates (1.5 min /d), with sows in large pens (17.6 m^2; 13.7 min /d;) intermediate (Hartsock and Barczewski, 1997). However, Lawrence et al. (1994) found no differences in time rooting substrates between sows in farrowing crates without bedding and in pens with straw bedding. More studies need to be conducted to determine if rooting behaviors are altered by lactational housing system.

II A 1 b. Postural behavior. Hartsock and Barczewski (1997) observed that from 72 to 49 (d -3) and 48 to 25 h (d -2) prepartum, sows in large pens stood longer (d -3: 246.2, d -2: 282.3 min/d) than sows in farrowing crates (d -3: 79.9, d -2: 141.0 min /d), with sows in small pens intermediate (d -3: 206.1, d-2: 254.9 min /d). However, Thodberg et al. (2002a) observed no difference in the start of the restless period, defined by the number of postural changes, between sows in farrowing crates and those in individual get-away pens and Lawrence et al. (1994) observed no postural behavior differences between sows housed in farrowing crates without bedding and those in straw bedded individual pens.

II A 1 c. Isolation and nest-site seeking phase summary. In summary, there is little information contained within the selected papers that describes the effects of farrowing system design on the behavior of sows during the isolation and nest-site seeking phase, and thus it is not possible to draw any conclusions about the welfare implications of farrowing system design, based on behavior, during this phase of farrowing. The complete expression of sow isolation and nest-site seeking behaviors are very difficult to accommodate within an indoor production system and are likely stymied in all of the available lactational housing systems. However, the systems vary in the amount of isolation provided and the degree of choice sows have in choosing their farrowing location and the impact of those factors on sow welfare is largely not elucidated. In addition, a better understanding of the potential welfare consequences that may result from compromised isolation and nest-site seeking behaviors in any of the current indoor lactational housing systems may aid in designing future systems to better address these behavioral needs.

II A 2. Nest building phase (24 h prepartum to birth of first pig). Nest building behavior, which involves an organized sequence of activities, begins approximately 24 h before the birth of the first piglet and peaks 12 to 6 h prepartum. Given the opportunity, sows will collect and use a variety of substrates to construct an elaborate nest into which she can burrow. Sows root out the chosen site by 5 to 10 cm; line the nest with grasses, roots, and leaves; and roof the nest with larger branches, grasses, and other fine materials. A number of studies have compared the behavior of sows in farrowing crates versus individual or group pens during this phase. However, like in the nest-site seeking and isolation phase, in some studies the housing system has been confounded with the amount or type of nesting substrate.

II A 2 a. Substrate directed and redirected behaviors.

Redirected substrate directed behaviors have been poorly investigated in systems without bedding. Hartsock and Barczewski (1997) found that sows in farrowing crates spent more time pawing than sows housed in either small or large square pens. Crated sows also spent more time rooting the floor than sows in small pens, with sows in large pens intermediate.

When sows in crates and individual pens have access to the same bedding or nesting substrates, the results fairly consistently indicate that sows housed in farrowing crates perform less nest-building than sows in individual pens and that nest-building peaks closer to the birth of the first piglet. Andersen et al (2014) compared farrowing crates with individual pens, both with chopped straw, and noted that crated sows chewed the pen fittings more and nest-built less than penned sows. In addition, the timing of nest-building differed such that nest-building behavior peaked at 7 h prepartum for crated sows and 9 h prepartum for penned sows. Temporal differences in nest-building were observed earlier by Damm et al. (2003) who reported that multiparous sows given access to straw in farrowing crates displayed peak nest-building 4 h prepartum, whereas sows in individual, Schmid pens displayed peak nest-building behavior 8 h prepartum. Crated sows also carried out less total nest-building (Damm et al., 2003). However, the results from a similar study that used primiparous sows and provided both branches and straw showed that penned gilts exhibited more straw and branch collecting behavior than crated gilts, but no other aspects of nest-building behavior were significantly affected by housing. (Damm et al. 2002). Although it could not be investigated statistically, the same study provided evidence that crated sows (9 h prepartum) nesting building behavior peaked later than penned sows (12 h prepartum).

A series of studies conducted at the SAC compared sow behavior in farrowing crates without bedding to behavior in bedded individual pens (Lawrence et al., 1994; Jarvis et al., 1997; 2001). In all the studies, crated sows consistently spent more time in fixture directed behaviors and overall engaged in less substrate directed behavior, which was primarily straw directed.

Thodberg et al. (2002a) compared nesting behavior among sows in farrowing crates with a small amount of chopped straw to sows in get-away pens that contained a roofed nesting area, sand floors, and a larger amount of long-stemmed straw. Crated sows began nest-building later and performed less nest-building than sows in the get-away pens.

Using a 2 (bedded, without bedding) x 2 (farrowing crate, individual pen) factorial design, Jarvis et al. (2002) observed that given the same amount of straw, straw use was greater among primiparous sows in individual pens than farrowing crates. Among the sows with access to straw, straw was the preferred substrate of sows, whereas the sows without straw redirected substrate directed behavior to the floor, bars, trough and drinker. Sow in pens without straw rooted the floor significantly more than sows in pens with straw and sows in crates with or without straw (Jarvis et al., 2002). Cronin et al. (1994) used the same treatments but presented only the main effects of bedding and housing and not their interactions. Crated sows pawed the floor more and rooted and nosed the floor and bars less than penned sows and sows without straw engaged in more pen fixture rooting and nosing. Additionally, providing straw tended to increase the sows' prepartum nesting behaviors (Cronin et al., 1994). Yun et al. (2014a, c) observed the sows performed less nesting behavior and more bar biting in farrowing crates than in the individual pen treatments. Between the pen treatments, sows provided straw exhibited more nesting behavior than those provided sawdust. Nesting behavior peaked at 7 h prepartum in pens with straw, 6 h prepartum in the pens with sawdust, and 4 h prepartum in the farrowing crates. Lastly, sows in individual pens with straw spent more time rooting and nosing the floor than sows in hinged crates with straw or conventionally crated sows without straw (Verhovsek et al. 2007).

II A 2 b. Postural behavior. Within systems without bedding, the research results fairly consistently suggest that housing sows in farrowing crates during the 24 h before parturition results in greater posture changing, lying, and sitting and less standing. Hartsock and Barczewski (1997) observed that sows in farrowing crates spent more time lying and less time standing and changed posture more than sows housed in either small or large square pens without bedding. Crated sows sat more than sows in small pens, with sows in large pens intermediate. However, in the last 2 h prepartum, neither the time spent in various postures nor the frequency of postural changes differed between sows in farrowing crates and rectangular pens without bedding (3.2 m^2; Biensen et al., 1996). Lou & Hurnik (1998) found conventionally crated sows spent more time lying laterally and sitting than sows in either circular or ellipsoid crates, in both of which the sow could turn around. Whereas, sows in the ellipsoid crates spent the most time standing. In addition, individually crated sows sat and lay more and stood and moved less than sows housed in a 10 sow group farrowing system without bedding (Weng et al., 2009a).

Sows in farrowing crates with straw have been observed to sit (Damm et al., 2003; Andersen et al., 2014), lay (Damm et al., 2003), and change posture (Damm et al., 2003) more than sows in individual pens with straw. However, in a similar study, housing did not influence the postural behavior of primiparous sows provided both branches and straw (Damm et al. 2002).

The research results from the studies comparing sows in farrowing crates without bedding to sows in bedded individual pens conducted at the Scottish Agricultural College show that crated sows consistently spend more time sitting and less time standing than the penned sows (Lawrence et al., 1994; Jarvis et al., 1997; 2001). However, Lawrence et al. (1994) observed crated sows spent more time lying sternally than penned sows, whereas Jarvis et al.

(2001) observed the opposite effect. Thodberg et al. (2002a) observed that crated sows changed posture more than sows in a straw bedded get-away pen.

Jarvis et al. (2002) found that primiparous sows housed in farrowing crates changed posture more, spent less time standing and walking, and were less active than sows in individual pens. But, providing straw to the sows did not affect sow activity. Cronin et al. (1994) also observed that crated sows changed posture more than penned sows. But unlike the previous results, sows provided with straw spent more time lying laterally and less time standing (Cronin et al., 1994). Verhovsek et al. (2007) reported that sows in farrowing crates without straw and sows in hinged crates with straw changed posture more and stood less than sows in individual pens with straw.

II A 2 c. Nest building phase summary. There is evidence that the behavior of sows in crates and individual pen systems differs in a consistent manner during the nest-building phase. In general, housing sows in farrowing crates results in increased posture changes, more time sitting and lying and less time standing. Nest-building behaviors peak closer to the birth of the first piglet in crated sows and there is more behavior directed at crate fittings. Where there is substrate available, it appears that sows in pens will carry out more substrate directed behavior than sows in crates. These differences could be interpreted as increased frustrated or thwarted nest-building behaviors among the crated sows. The inability to complete nest building behaviors in a timely fashion has the potential to interfere with parturition. However, it is also likely that straw alone cannot ameliorate the frustrated nesting. Thus, more studies are needed to explicate how the type and amount of substrate material impacts nesting behaviors in different lactational housing systems.

II B. Sow Physiology

II B 1. Cortisol. During the nesting phase, 5 studies conducted by a single laboratory group at the SAC (Lawrence et al., 1994; Jarvis et al., 1997, 2001; 2002) have found greater cortisol concentrations among sows housed in stalls than in individual pens. In addition, one of the studies (Jarvis et al., 2002) determined that providing straw to stall housed sows was not sufficient to eliminate the cortisol concentration differences between sows housed in stalls and pens. The cortisol differences suggest that during the nesting phase stall housing increases the sow's stress response. However, it is important to note that as only one research group has measured cortisol differences, study replication using different genetics and management is needed to confirm this effect.

II B 2. Heart rate. In addition, the single study that examined sow heart rate found no differences among housing systems from gestational day 113 until 1 h prior to farrowing. In the last hour before farrowing, crated sows had a higher heart rate than penned sows (Damm et al., 2003).

II B 3. Reproductive hormones. Sow housing does not appear to influence reproductive hormone concentrations in the nesting phase. None of the studies have identified differences in either prolactin (Lawrence et al., 1994; Damm et al., 2002; Yun et al., 2013), progesterone (Biensen et al., 1996; McLean et al., 1998; Oliviero et al., 2008), or oxytocin (Lawrence et al., 1995; Damm et al, 2002; Yun et al., 2013) concentrations between stall housed and individually penned sows. It is noteworthy to mention that the definition of the nesting phase was not consistent among the studies which led to samples being taken at different times and the results aggregated differently. In some cases authors combined the data for the entire day prior to the first pig (Biensen et al., 1996; McLean et al., 1998; Oliviero et al., 2008), or even the 3 days prior (Yun et al., 2013; Yun et al., 2014a). In these cases there were no treatment differences as stated above; however, it is possible that these differences were missed.

II B 4. Sow physiology summary. There is some evidence that the physiology of sows housed in farrowing crates and individual pen systems differs in a consistent manner during the nesting phase. Cortisol concentrations are greater in sows housed in crates than those housed in pens as is heart rate immediately before farrowing onset. Both measures can be interpreted as being indicative of an elevated stress response among the sows housed in farrowing crates. However, no differences were reported between crates and pens for reproductive hormones such as prolactin, progesterone, and oxytocin. Taken together these studies are still quite limited. Thus, our understanding of the welfare implications for different lactational housing systems during the nesting phase would be bolstered by studies of other stress physiology markers and or repetition of ones mentioned above using different genetics or facilities.

III. Farrowing and Neonatal Phase (first pig until 3 d postpartum)

III A. Sow Behavior

III A 1 Farrowing phase. Farrowing often begins a few hours after nest-building peaks. This phase can be considered as lasting from the birth of the first piglet to the birth of the last piglet. The sow is unusually passive for an ungulate and once parturition is underway she carries out very few postural changes. Sows often stand, turn, and sniff the first piglets born (Jensen, 1986), but this behavior declines as more piglets are born. Sows do not get up to help the neonates from their fetal membranes and the umbilical cord is normally torn as the piglet moves to the sow's udder. For the first 48 h after farrowing has ended, sows are inactive for 90 to 95% of the time.

III A 1 a. Nest-building and postural behaviors. A comparison of sows in farrowing crates and individual pens, both with straw, found that 6 out of 8 sows continued some nest-building behaviors during parturition, but there was no quantifiable difference between housing systems (Damm et al., 2003). Likewise, Biensen et al. (1996) and Verhovsek et al. (2007) observed no differences in the number of postural changes during farrowing between sows in individual pens or crates whether or not straw bedding was provided. Conversely, Nowicki & Schwarz (2010) noted that crated sows carried out more posture changes than individually penned sows, but time spent in various postures and rolling behaviors did not differ between housing systems. However, the results from other studies have shown that sows in individual pens spend more time standing (Yun et al., 2014a), walking (Cronin et al., 1994), and active (Thodberg et al. 2002a) than sows in farrowing crates.

III A 1 b. Parturition duration. A number of studies have compared the duration of parturition and the birth interval between individual piglets in farrowing crates and individual pens, but in some cases housing system has been confounded with the type or amount of nesting substrate provided.

Comparing farrowing crates with individual pens, neither with bedding, Biensen et al. (1996) found inter-birth interval (IBI) was longer for crated sows; however Jarvis et al. (2004) observed no differences in IBI between the housing systems. When bedding substrate is the same in both crates and individual pens, the housing system does not seem to influence farrowing duration or IBI (branches, peat, straw: Damm et al., 2002; straw: Damm et al., 2003; chopped straw: Pedersen et al., 2011a).

Some research studies in which housing type and substrate co-vary have shown that crated sows without bedding (Oliviero et al., 2008; 2010) or crated sows with chopped straw (Thodberg et al., 2002a) had longer parturition durations and IBIs compared with sows housed in individual pens with more bedding. A single study that compared 3 treatments 1) crated sows without straw, 2) crated sows with straw, and 3) individually penned sows with straw found that penned sows had shorter IBIs than sows in either crated treatment (Verhovsek et al., 2007). In contrast to the previous results, a series of studies conducted at the Scottish Agricultural College (SAC) in Edinburgh compared sows in farrowing crates without bedding with sows in pens with straw and found no effect of treatment on parturition duration or IBI (Lawrence et al., 1995; Jarvis et al., 1998; 1999a; 2000). Although, Lawrence et al. (1995) reported that early in parturition, IBI was shorter for the second and third piglets of the litter among the crated sows than the penned sows.

In general, more studies found no effect of housing treatment on farrowing duration than studies found a difference. Where differences exist, farrowing durations and IBIs would appear to consistently be longer for sows housed in crates than in pens, but in nearly all cases, housing type is confounded with the provision of substrate.

III A 1 c. Farrowing phase summary. There is little information on sow behavior during farrowing and results are inconsistent. Few studies exist that have looked exclusively at the effects of farrowing environment on the behavior of the sow during the parturition period. Some studies include parturition within a longer time frame (e.g. d 0 or 1 after farrowing) but do not allow for the time during actual farrowing to be disentangled from a longer time period that includes post-farrowing time. In part, studies may be lacking because the sow has been described as being largely passive during parturition (Jensen, 1986; Jarvis et al., 1999b; Pedersen et al., 2003). However, it is clear that environmental factors affect sow behavior even during parturition and more work on farrowing behavior is needed for a better understanding of the welfare impact of lactational housing type.

III A 2. Early lactation (d 0 to 3 phase). This period, part of the nest occupation phase, can be considered as being from the birth of the last piglet to 3 d postpartum.

III A 2 a. Postural behavior. It is during this time period that the greatest proportion of piglet mortality occurs, much of it due to overlying or crushing by the sow, and thus her posture-changing and responsiveness to piglet distress at this time are of particular interest. A number of studies have reported no differences in posture or posture changes between sows housed in farrowing crates and either individual pens (Blackshaw et al., 1994; Cronin et al., 1994; Biensen et al., 1996), sow pair pens (Cronin et al. 1996), or group pens (Arey and Sanchez, 1996). However, other studies have found that crated sows spend more time sitting (Lou and Hurnik, 1998; Thodberg et al., 2002b; Nowicki & Schwarz, 2010) and lying (Thodberg et al., 2002b), spend less time walking (Cronin et al. 1994), and are less active (Thodberg et al., 2002b) than sows in individual pen systems.

Sows in farrowing crates have been reported to change posture both more (Thodberg et al., 2002b; Nowicki & Schwarz, 2010) and less (Verhovsek et al 2007; Melišová et al., 2012) than sows in individual pens during this early lactation period. However, the type of posture change and the sow and piglet interactions are more important than the total number of posture changes (Marchant et al., 2001). Bradshaw and Broom (1999) compared crates with oval pens and found that dangerous rolling-over posture changes were more frequent in the oval pens.

Likewise, Melišová et al. (2012) found the frequency of piglets being trapped during posture changing was higher when the sows were housed in individual pens than crates. Cronin et al. (1996) found that sows in sow pair pens investigated and vocalized to their piglets more and were more likely to nose or paw the floor prior to lying down than sows in farrowing crates. Finally, it has been consistently shown that sows in individual and pair pens are more responsive to tests involving playback of piglet squeals or stimulated own piglet squeals than sows in crates (Cronin et al., 1996; Thodberg et al., 2002b; Nowicki & Schwarz, 2010; Melišová et al., 2012), but not to squeals of piglets actually being crushed (Melišová et al., 2012).

III A 2 b. Sow-piglet interactions. There are a number of studies that have investigated sow-piglet interactions after farrowing, but only 2 studies have reported data on sow-piglet interactions within the first 3 d postpartum as stand-alone data. One study reported that from the birth of the first pig until 8 h after the birth of the first pig, sows in farrowing crates and individual pens, both with chopped straw, did not differ in the amount of time spent sniffing piglets (Andersen et al., 2014). The other study reported that primiparous sows in individual pens expressed more piglet directed behavior than primiparous sows in farrowing crates, especially during the early part of parturition, whereas later in parturition, the penned sows were less responsive to piglets that approached their heads than the crated sows (Jarvis et al., 2004).

III A 2 c. Early lactation phase summary. In summary, given the importance of this time period, again there is scarce information about sow behavior. Very few papers have looked for differences in behavior for short time periods or separate days after farrowing; instead many studies have combined the immediate post-farrowing period with data collected throughout lactation. There are not enough data to be able to determine whether different types of alternative housing systems (e.g. individual pens, group pens, hinged crates, etc.) have consistent effects on sow postural changes or sow-piglet interactions or how whether flooring type and bedding substrate affects post-farrowing behavior. Thus more studies are needed to address these questions.

III B. Sow Physiology

III B 1. Cortisol. Unlike the nesting phase, cortisol concentration does not seem to be influenced by housing type in the farrowing and neonatal phase. Seven studies, conducted in the same laboratory, indicate that crated and individually penned sows exhibit similar cortisol responses (Lawrence et al., 1994; Jarvis et al., 1997, 1998, 1999a, 2001, and 2004). The blood samples were obtained from immediately after the birth of the first pig (Lawrence et al., 1994; Jarvis et al., 1997; 1999a; 2001) until 2 d later (Jarvis et al., 1998).

III B 2. Reproductive hormones. Like the nesting phase, no differences have been observed in either prolactin (Lawrence et al., 1994; Damm et al., 2002; Farmer et al., 2006) or progesterone (McLean et al., 1998; Oliviero et al., 2008) concentrations among sows housed in crates or individual pens in the farrowing and neonatal phase. The prolactin samples were collected from the birth of the first pig (Lawrence et al., 1994; Damm et al., 2002) until 2 d postpartunpostpartum (Lawrence et al., 1994; Farmer et al., 2006) and the progesterone samples were collected from the birth of the first pig (McLean et al., 1998) until 3 d postpartum (Oliviero et al., 2008).

Some research results have shown that sows in individual pens exhibit greater oxytocin concentration during parturition (Oliviero et al, 2008) and from 2 to 4 h postpartum (Lawrence et al., 1995) compared with sows in crates. However, other studies have found no differences in oxytocin concentrations in the postpartum period (Gilbert et al., 1996; Jarvis et al., 2004; Yun et al., 2013; Yun et al., 2014b). In addition, Oliviero et al. (2008) found greater concentrations of oxytocin were negatively associated with farrowing time, whereas Yun et al (2014b) observed no relationship between oxytocin and farrowing time. These differing outcomes may be related to differing genetics, specifics of housing and management, and sample collection timing.

III B 3. Sow physiology summary. There is little evidence lactational housing system impacts sow physiology during the farrowing and neonatal phase. However, with the exception of cortisol, the data about sow physiology are sparse and in some cases inconsistent. Our understanding would be strengthened by repetition of some of these studies especially those yielding contradictory results as well as the study of other physiological indicators of welfare such as heart rate.

III C. Piglet Behavior

III C 1. Nursing behavior. Few studies have compared nursing behavior of neonatal pigs housed in farrowing crates with other housing systems. Pedersen et al. (2011a) observed no difference in the latency to first suckle between pigs born in a farrowing crate and an individual pen. On the day after birth, piglets in farrowing crates, circular crates, and ellipsoid crates spent 10.0, 11.7, and 15.3%, respectively of the time nursing, but these percentages were not compared statistically (Lou and Hurnik, 1998). Circular and ellipsoid crate allowed the sow to turn around. Arey and Sancha (1996) observed piglets spent more time nursing in the group pens than the farrowing crates on d 1, but not d 3, postpartum. However, Cronin et al. (1996) saw no differences in nursing behaviors between piglets housed in sow-pair pens or farrowing crates.

III C 2. Piglet behavior summary. There is little information on piglet behavior during farrowing and neonatal phase with regard to lactational housing type and much of what is reported is not consistent. Given that successful nursing is prerequisite for receiving adequate colostrum and colostrum is crucial for piglet welfare, more research needs to be conducted to determine how housing system influences piglet nursing behavior during the neonatal phase.

III D. Piglet Performance

III D 1. Litter size. Total litter size does not seem to be affected by farrowing housing. Total litter size in individual pens (Kutzer et al., 2009; Oliviero et al., 2010; Ringgenberg et al., 2012; Moustsen et al., 2013) and group pens (Cronin et al., 1996, 2000; Jarvis et al., 1999a; Marchant et al., 2000; Kutzer et al., 2009; Bohnenkamp et al., 2013; Hales et al., 2014) does differ from that in farrowing crates. Even so, total litter size may be influenced by an interaction between sow genetics and lactational housing system. Sows selected for improved piglet survival in individual pens farrowed larger total litters in individual pens than in farrowing crates (Pedersen et al., 2011a). Likewise, sow parity may also influence the effect of housing on litter size. Marchant-Forde (2002) reported that primiparous, but not multiparous, sows in farrowing crates gave birth to larger litters than those in group pens.

Given the lack of differences in total litter size, is unsurprising that farrowing system has minimal effect on the number of pigs born alive. Most studies demonstrated no difference in the number of pigs born alive between farrowing crates and individual pens (Lawrence et al., 1994; Biensen et al., 1996; Cronin et al., 2000; Jarvis et al., 2005; Weber et al., 2007; Gu et al., 2011; Ringgenberg et al., 2012; Moustsen et al., 2013; Hales et al., 2014; Yun et al., 2014b,c) or group pens (Cronin et al., 1996; Marchant et al., 2000; Bates et al., 2003; Weng et al., 2009b; Bohnenkamp et al., 2013c). However, Lou and Hurnik (1994) observed sows housed in circular and ellipsoid crates, which allow the sow to turn around, bore more live pigs than sows housed in farrowing pens.

III D 2. Stillborn pigs and dystocia. The differences in live litter size may have resulted from fewer stillbirths in the individual pens as sows in individual (Lou and Hurnik, 1994; Jarvis et al., 1999; Oliviero et al,. 2010; Gu et al., 2011) and group (Arey and Sancha, 1996; Marchant-Forde, 2002; Weng et al., 2009b) pens are often reported to bear fewer stillborn pigs than sows in farrowing crates. In addition, Cronin et al. (2000) reported that sows housed in individual pens received less farrowing assistance than those housed in crates. It is unclear whether this was due to a true difference in parturition or whether it was a result of stockperson reluctance to assist when the sow was able to move around. Management and animal handling in pen systems is an area that is likely to be of great importance; however it is an area with sparse information and therefore needs further investigation.

III D 3. Piglet performance summary. Neither the total nor live litter size appears to be influenced by lactational housing system. A large number of studies support this conclusion. However the impact of housing type on number of stillborn piglets did vary some between studies. Our understanding would be improved by additional studies comparing stillbirth rates among different lactational housing types, especially after taking care to control for possible confounding factors such as pre-farrowing experiences and also additional studies that examine the role of management and animal handling in alternative housing systems.

IV. Lactation Period (4 d postpartum to weaning)

IV A. Sow Behavior

IV A 1. Nest occupation and social integration. Nest occupation occurs for 7 to 10 d postpartum. Maternal behavior has a very complex organization mainly revolving around the suckling event. Nursing can be initiated either by the sow lying on her side and presenting her teats or by the piglets squeaking at her head and massaging the teat area. Eventually the whole litter vigorously butts and jostles for position at the mammary glands, with or without attaching themselves to the nipples. Often at this time piglets vocalize intensely and continually (Appleby et al., 1999). While the sow rapidly grunts, the whole litter becomes quiet, with each piglet suckling a nipple; this phase can last between 7 and 38 s (average 15 s). It is followed by another phase of active stimulation during which the piglets butt at and nose the udder which extends from less than 1 min to several minutes. The latter phase ends when piglets detach themselves from the teats, fall asleep, or engage in other activities or the sow terminates the nursing by standing up or rolling onto her sternum to hide her teats (Johnson and Marchant-Forde, 2009).

In a free-range situation, the sow and piglets stay away from the rest of the herd for at least the first week postpartum (Jensen, 1988). Later she leaves the nest for longer times periods, forages further away from the nest, and eventually, on average7 d postpartum, rejoins the herd for morning feeding. The litter continues to use the nest for an additional 2 to 3 d, after which the nest is abandoned. Free-range sows begin socially integrating their litter into the herd near the end of the second week postpartum (Jensen, 1988) and the process continues gradually for several days. The extended isolation allows time for family bonding to become complete before the piglets are introduced to other litters. Herd introduction results in a shift of social interactions away from litter-mates and towards other piglets of a similar age (Petersen et al., 1989).

IV A 1 a. Response to piglet vocalizations. Sows housed in group pens during lactation may respond more to piglet vocalizations than sows housed in farrowing crates. In response to piglet vocalizations, lying group housed sows (76.1%) were more likely to stand than crated sows (34.9%; Arey and Sancha, 1996) and sows in pair-pens were more likely to stop feeding and spent more time not feeding than crated sows (Cronin et al., 1996). Additionally, sows in the pair-pens grunted more toward the test piglet than sows in farrowing crates (Cronin et al., 1996). However, the percentage of time spent nosing piglets did not differ between sows housed in farrowing crates and a group pen system (Arey and Sancha, 1996), but naso-naso contact between the sow and piglets was greater in farrowing crates than in individual pens with round crates, in which the sows could turn around, intermediate (Blackshaw et al., 1997).

IV A 1 b. Substrate directed behavior. Few studies have examined the effects of farrowing housing system on substrate directed or nesting behaviors during the lactation phase, but the results suggest farrowing crates inhibit the expression of those behaviors. Sows in group pens have been observed to spend more time exhibiting substrate directed (Arey and Sancha, 1996) and rooting behaviors (Weng et al., 2009a) than sows in farrowing crates. Likewise, primiparous sows in straw bedded, individual pens (10.3%) spent more time exhibiting substrate directed behavior than sows in crates with (5.2%) or without straw (6.8%; Jarvis et al., 2006). Study replication will be needed to confirm the results of these trials.

IV A 1 c. Postural behavior. Like substrate related behavior, farrowing crates appear to depress sow activity when compared with individual pens. Sows in farrowing crates have been observed to sit more (Blackshaw et al., 1994; Jarvis et al., 2006), lay more overall (Blackshaw et al., 1994), and lay more laterally (Jarvis et al., 2006) and stand less (Devillers and Farmer, 2008) than sows in individual pens. Similarly sows in farrowing crates have been observed to sit (Cronin et al., 1996; Weng et al., 2009a), lay inactively (Arey and Sancha, 1996), and lay laterally (Weng et al., 2009a) more and stand (Cronin et al., 1996; Weng et al., 2009a) and move (Weng et al., 2009a) less than sows in group pens. Although some study results show no difference in sitting (Arey and Sancha, 1996; Ringgenberg et al., 2012; Bohnenkamp et al., 2013a), lying (Cronin et al., 1996; Ringgenberg et al., 2012; Bohnenkamp et al., 2013a), and standing (Blackshaw et al., 1994; Arey and Sancha, 1996; Ringgenberg et al., 2012; Bohnenkamp et al., 2013a) behaviors between crated and group or individually penned sows, no studies reported greater activity among the crated sows. Increased lying in the farrowing crates, in particular lateral lying with the nipples exposed, may be related to nursing behaviors and therefore benefit the piglets. Enrichment may also influence postural behavior as sows in a highly enriched individual pen were scored as being more careful while lying down than sows in a crate with a bucketful of sawdust (Yun et al., 2013).

IV A 1 d. Sow behavior summary. There is some evidence that the behavior of sows in farrowing crates and individual pen systems differs in a consistent manner during the lactation period. Sows housed in crates are less responsive to piglet vocalization, spend less time engaged in substrate directed behaviors, and are less active. However, the findings on responsiveness to piglet vocalization and substrate directed behaviors come from a limited number of research studies. In contrast, the results demonstrating decreased sow activity in farrowing crates have been replicated by several research studies from different research groups. But although no studies reported increased activity during lactation for sows in crates, several other studies reported no influence of lactational housing system differences on sow activity. Taken together, these results suggest that farrowing crate housing restricts sow behavioral expression and therefore can negatively impact sow welfare during lactation. Furthermore, sow failure to respond to piglet vocalizations also portends decreased piglet welfare. Our understanding of the implications of lactational housing on sow behavior would benefit from repetition of the studies on responsiveness to piglet vocalizations particularly using current genetics and housing systems as well as new studies that better document sow-piglet interactions during onset and cessation of nursing.

IV B. Sow Physiology

IV B 1. Cortisol and heart rate. Very few research studies have examined sow physiology during the lactational phase. In fact, no studies have compared cortisol concentrations or heart rate between crated sows and sows in alternative farrowing systems.

IV B 2. Reproductive hormones. Like the previous phases, neither prolactin nor progesterone concentrations were influenced by farrowing system. Prolactin samples were obtained from d 1 to 7 (pooled; Yun et al., 2013), on d 7 (Lawrence et al., 1994), and on d 20 (Farmer et al., 2006) postpartum, whereas progesterone samples were obtained on d 4 and 5 (Oliviero et al., 2008) and on d 7 (McLean et al., 1998) postpartum. In addition, the farrowing housing did not affect oxytocin concentrations from d 1 to 7 (pooled; Yun et al., 2013) or on d 7 (Lawrence et al., 1995) postpartum. Again with the limited number of studies, it is possible that differences in hormonal concentrations could be obscured due to pooling of data and sampling times.

IV B 3. Sow physiology summary. The lactation period represents the biggest void in our understanding of how sow physiology is impacted by different lactational housing systems. Some behavioral indicators suggest decreased sow welfare during this phase. Thus, it also would be important to examine physiological indicators of the stress response such as cortisol and heart rate. Given the duration of lactation, possible measures of chronic stressors such as natural killer cell toxicity or lipopolysaccharide-induced proliferation of lymphocytes also should be examined.

IV C. Sow Performance

IV C 1. Feed intake. The results from studies examining the effect of farrowing system on feed intake are not consistent. Some authors have demonstrated greater feed intake (Cronin et al., 2000; Farmer at al., 2006) and less weight loss (Farmer et al., 2006) when sows are housed in individual pens and greater feed intake in group pens (Bohnenkamp et al., 2013c) compared with farrowing crates. Whereas, Ringgenberg et al. (2012) observed the opposite outcome so that sows in farrowing crates ate more feed than sows in individual pens. Additionally, other studies reported that feed intake did not differ between sows housed in individual (Biensen et al., 1996) or group (Marchant et al., 2002) pens and those housed in farrowing crates. Interactions between lactational housing system and other factors, such as sow genetics, sow parity, and pen design, may have influenced feed intake and affected the differing outcomes. For example, Farmer et al. (2006) observed greater feed intake among individually penned sows than crated sows, but only among the sows housed at high ambient temperatures and not the sows housed in a thermoneutral environment.

IV C 2. Weight. Paralleling their feed intake results, Ringgenberg et al. (2012) reported greater weaning weights among crated sows than individually penned sows and Farmer et al. (2006) observed a lactational housing system by season interaction, in which the individually sows weighed more than the crated sows, but only when housed at elevated temperature. However, most studies report that lactational weight loss does not differ between sows housed in group pens (Marchant-Forde, 2002; Weng et al., 2009b) or individual pens (Ringgenberg et al., 2012) compared to farrowing crates. Likewise, there is no evidence that pen housed sows weigh more at weaning (Marchant-Forde, 2002) or have greater back fat depths after farrowing (Ringgenberg et al., 2012) or at weaning (Ringgenberg et al., 2012). So, although pen lactational housing systems benefit sow behavioral needs, they do not seem to benefit to sow performance. Additionally, the long term effects of alternative farrowing housing systems on sow performance is unknown and needs further research.

IV C 3. Sow performance summary. There is limited information available on sow feed intake and weight changes during the lactation period with regard to lactational housing type and much of what is reported is not consistent. Several factors other than housing type could contribute to both feed intake during lactation and subsequent weight changes. Additional studies are needed that compare these measures in different housing systems that adequately consider the role of ambient temperature, litter size, lactation length, caloric density of feed, feeding schedule, sow prepartum condition, sow parity, and sow genetics.

IV D. Piglet Behavior

IV D 1. Nursing behavior. Nursing behavior appears to be influenced by lactational housing system, but the study results are inconsistent. In a group pen system, piglets have been observed to spend more time nursing than in farrowing crates (Arey et al., 1996). In a different study, piglets have been observed to nurse more successfully, but less frequently, in the group pen than in a farrowing crate without a difference in total nursing time (Weng et al., 2009a). Whereas, crated piglets have been observed nursed longer in total (Blackshaw et al., 1994) and successfully (Yun et al., 2013) than those in individual farrowing pens with or without nesting material. However, Yun et al. (2013) observed no differences in the frequency of successful nursings. Pedersen et al. (2011b) also observed longer nursings in farrowing crates than individual pens, but only for piglet terminated nursings which occurred more in the crated system. Other studies comparing farrowing crates with individual pens, with or without substrate, (Oostindjer et al., 2011; Pedersen et al., 2011a; Ringgenberg et al., 2012) or group pens (Cronin et al., 1996; Bohnenkamp et al. 2013a) have found no effect of farrowing housing system on piglet nursing behavior.

Other factors, such as sow parity and ambient temperature, may interact with housing to influence nursing behavior. Piglets born to primiparous sows in individual get-away pens nursed longer and more frequently at d 10 postpartum than those born in farrowing crates. However, nursing behavior did not differ between housing systems among piglets born to older sows (Thodberg et al., 2002). Devillers and Farmer (2008) observed more frequent successful nursings in farrowing crates than in an individual pen system, but that this behavior was also affected by ambient temperature.

Udder massage does not seem to be strongly influenced by lactational housing, but there are few studies that compare farrowing crates to other housing systems. Like nursing duration, if the piglets terminated the nursing, post-nursing udder massage lasted longer in farrowing crates than individual farrowing pens, but crated piglets terminated more nursings than penned piglets (Pedersen et al., 2011). In contrast, on d 5 postpartum Cronin et al. (1996) observed no difference in time spent massaging the udder between piglets reared in farrowing crates or those reared in a group pen system (Cronin et al., 1996).

IV D 2. Play behavior. The effects of lactational housing system on the pre-weaning play behavior of piglets are unclear. Few studies have compared play behavior and their results conflict. Prior to weaning, piglets reared in group pen systems have been shown to spend more time playing than crated piglets (Arey et al., 1996). In addition, Chaloupková et al. (2007a) found that piglets reared in an enriched farrowing pen tended to perform more locomotor and social play than piglets reared in unenriched conventional crates. However, Blackshaw et al. (1997) found that piglets reared in round crates, allowed the sow to turn around, spent more time performing individual (running and springing) and social play (nudging and playing with the sow) behaviors than piglets reared in individual pens. And Oostindjer et al. (2011) observed no differences in play behavior between individually penned and crated piglets.

IV D 3. Belly-nosing and aggressive behaviors. In the single study that compared farrowing crates with an alternative farrowing system, belly-nosing and aggressive behaviors were not influenced by lactational housing (Oostindjer et al., 2011).

IV D 4. Piglet behavior summary. During the lactation period, the majority of the behavioral data appears to be contradictory. It is difficult to conclude whether alternative farrowing systems have a positive impact on nursing and play behaviors and help prevent negative behaviors such as belly nosing and aggression. The variability in the behavior data is likely due, at least in part, to the variety in alternative farrowing systems described in the literature. Also the dimensions of the conventional farrowing crates differed across papers, which could also impact piglet behavior. Of course there other variables which could influence the behavioral response of piglets in these studies, including pig genetics, ambient temperature, management system etc. Furthermore, the inconsistency in how behavior was measured could also account for the inconsistencies in results among studies. It would be useful for researchers to agree on behavioral measures that assess nursing of piglets, so that results from different studies can be more easily compared in the future. In addition, many of these studies need to be repeated following efforts to address possible sources of variation contributing to the outcomes.

IV E. Piglet Performance

IV E 1. Mortality. Arguably, piglet mortality is the most important performance indicator as it gives us the most information about the housing system and the sow's rearing ability. Several reviews have attempted to summarize performance information in alternative farrowing systems (Edwards and Fraser, 1997; Baxter et al., 2012). However, as those authors suggested summarization can result in a loss of the study details that explicate performance results. Sow genetics, parity, and previous experiences; the similarity between gestational and lactational housing; and litter size can all influence piglet survival and their influences may interact with the effects of the lactational housing system (Damm et al., 2002; Marchant et al., 2002; Thodberg et al., 2002; Bates et al., 2003; Canario et al., 2006; Weng et al., 2009b; Baxter et al., 2013;

Rutherford et al., 2013). Additional factors, such as management and animal handling, are often reported anecdotally and may influence performance and require further investigation.

IV E 1 a. System differences in mortality. Alternative lactational systems vary greatly in their performance. Some studies report higher mortality in individual pens compared with farrowing crates (Blackshaw et al., 1994; Bradshaw and Broom 1999; Moustsen et al., 2013; Hales et al., 2014). Whereas, other studies report no differences in in piglet mortality (Cronin et al., 2000; Jarvis et al., 2004; Weber et al., 2007; Pedersen et al., 2011a; Melišová et al., 2014); however no studies report lower mortality in individual pens than farrowing crates. Preweaning mortality in group pens has also been reported as greater (Marchant et al., 2000; Bates et al., 2003) or not different (Arey and Sancha, 1996; Kutzer et al., 2009) than that in farrowing crates. Few studies have been conducted in hinged crates, but Moustsen et al. (2013) reported that as long as the sow was crated for at least 4 d, pre-weaning mortality did not differ between the hinged and farrowing crates.

IV E 1 b. Differences in cause of mortality. It has been repeatedly demonstrated that piglet crushing is higher when sows are housed in individual (Jarvis et al., 2005; Weber et al., 2007; Ringgenberg et al., 2012; Moustsen et al., 2013) or group pens (Marchant et al., 2000; Kutzer et al., 2009); however other death causes, such as starvation, low viability, and diarrhea, are more prevalent when sows are crated (Cronin et al., 1996; Weber et al., 2007; Kutzer et al., 2009; Pedersen et al., 2011a).

IV E 2. Litter size weaned. The number of pigs weaned depends on the number of piglets born alive and the pre-weaning mortality. Therefore, alternative lactational housing systems either have fewer or similar numbers of pig weaned as crated systems. The majority of studies demonstrate no differences in the number of pigs weaned between individual (Weber et al., 2007; Kutzer et al., 2009; Ringgenberg et al., 2012) or group (Cronin et al., 2000; Kutzer et al., 2009; Bohnenkamp et al., 2013) pens and farrowing crates, although several studies have reported fewer piglets weaned in individual pens than crates (Pedersen et al., 2011a; Moustsen et al., 2013). Like birth litter size, Marchant-Forde (2002) reported that primiparous sows housed in farrowing crates weaned larger litters than those housed in group pens, but among the multiparous sows lactational housing system did not influence the litter size at weaning.

IV E 3. Weight. Regardless of litter size at weaning, there is evidence that piglet weaning weights are greater in lactational housing systems where the sow can move around (individual pen: Farmer et al., 2006; Melišová et al., 2014; group pen: Li et al., 2012; hinged crate: Pedersen et al., 2011b) than in farrowing crates. However, several studies report lower wean weights among pigs reared in group pens than farrowing crates (Bates et al., 2003; Bohnenkamp et al., 2013c) or no weight differences at weaning between pigs raised in crates and group pens (Bohnenkamp et al., 2003b). Differential nursing behaviors among the systems may account for some of the weight differences. Farmer et al. (2006) observed no difference in milk composition between sows housed in farrowing crates and individual pens which supports the hypothesis that nursing success rather than milk affects weight gain. Yun et al. (2014c) reported a tendency for higher serum immunoglobulin G and A concentrations from piglets born to sows that were housed in an enriched pen during the nesting phase, suggesting that early colostrum intake is enhanced when sows can nest-build satisfactorily. However, like the differences in weaning weight, reports of differences in nursing behaviors are inconsistent among the research studies. Therefore more research is needed to determine which aspects of a lactational housing systems support successful nursing and weight gain.

IV E 4. Piglet performance summary. Findings on piglet performance during lactation between those animals raised in individual farrowing pens versus farrowing crates remains equivocal. Several studies demonstrate that pen reared piglets have increased pre-weaning mortality and consequently constitute smaller litter sizes at weaning compared with crate reared piglets. However, several studies also report similar pre-weaning mortality between pens and crates. Stillbirth rates are lower in pens, whereas deaths due to crushing are higher in pens. Weaning litter weights tend to be inversely related to pre-weaning mortality and therefore are similar or lower in individual pens compared to crates. Group pen farrowing systems typically have higher pre-weaning mortality and lower weaning weights compared to individual pens or crates. Taken together, these findings highlight the fact that piglet performance in pen based farrowing systems can sometimes, but not always, match piglet performance in crated lactational systems. It is rare for the pen based farrowing systems to do better than crated systems as supported by the most recent research studies. Future experiments need to focus on understanding why pen based systems only sometimes perform as favorably as crates and in particular examine the role of humans in the success of these alternative housing systems.

V. Post-weaning Period (weaning until slaughter)

V A. Sow Performance

V A 1. Wean to estrus interval. Weng et al. (2009b) reported that sows housed in electronic sow feeder pens in gestation followed by farrowing crates during lactation (5.36 d) had a longer wean to estrus interval than sows housed in electronic sow feeder pens in gestation followed by group pens during lactation (-3.6 d). However, the negative number indicates that the group housed sows returned to estrus prior to weaning, which may be disadvantageous as it can disrupt all-in-all-out systems and risks being missed by the farm staff which may result in the missed sow becoming desynchronized from her group. In contrast, Biensen et al. (1996) observed no difference in wean to estrus interval among sows housed in farrowing crates and individual pens, a result that was replicated by Ringgenberg et al. (2012).

V A 2. Sow performance summary. Although only a limited number of studies have been conducted, there is little to no evidence supporting an effect of lactational housing system type on sow performance post-weaning. Repetition of these original or similar studies as well as studies that follow sow performance through a subsequent parity would be of interest in terms of understanding how lactational housing system might impact the long term performance of sows.

V C. Piglet Behavior

V C 1. Weaning. Like social integration, natural weaning is a gradual event. Weaning starts early as suckling frequency declines gradually after the first week of lactation and the number of sow terminated suckling events increases, events which might indicate the sows decreasing inclination to nurse (Jensen, 1993). Piglets begin to consume solid food around 4 wk postpartum and by 8 wk of age, solid food constitutes a large part of the piglets' diet (Jensen, 1995). Weaning is completed between 8 (Newberry and Wood-Gush, 1985) and 19 (Jensen and Stangel, 1992) wk postpartum.

V C 1 a. Play behavior. Oostindjer et al. (2011) observed that piglets that were housed in individual farrowing pens prior to weaning performed more play behavior after weaning than piglets housed in farrowing crates prior to weaning.

V C 1 b. Belly-nosing behavior. During the first 2 wk after weaning, piglets that had been reared in farrowing crates prior to weaning spent less time performing belly-nosing behavior than piglets that had been reared in a group pen system (Li et al., 2012). Conversely, Oostindjer et al. (2011) found that piglets reared in farrowing crates performed more belly-nosing behavior during the post-weaning period than piglets reared in single litter farrowing pens.

V C 1 c. Aggressive behaviors. During a feed competition test performed at 3 and 6 mo of age, piglets that had been reared in an enriched, individual farrowing pen displayed fewer aggressive interactions than piglets that had been reared in an unenriched farrowing crate (Chaloupková et al., 2007a). However, the lactational housing system did not influence aggressive behavior after mixing at weaning (Chaloupková et al., 2007a). Kutzer et al. (2009) compared aggressive behavior at weaning among piglets originating from conventional farrowing crate, individual pen, and group pen lactational housing systems. At 10 d postpartum, some of the farrowing crate and individual litters were allowed to co-mingle with other litters which created 5 treatment groups. The intensity of fighting and biting at weaning was lower among the group pen housed and co-mingled piglets compared with the piglets that had not been exposed to other litters, but aggression did not differ by housing type alone. Both Bohnenkamp et al. (2013c) and Li and Wang (2011) observed greater aggression at weaning among piglets reared in farrowing crates than group pens; however as the crated piglets in those experiments were not co-mingled prior to weaning the relative roles that social interaction and space allowance and complexity play in the outcomes remain unclear.

V C 1 d. Piglet behavior summary. During the post-weaning period, alternative farrowing systems may increase the performance of play behavior among piglets and reduce aggression, whereas the effect of housing system on belly-nosing behavior was inconsistent. However, only 1 study examined play behavior and in several experiments farrowing pen design was confounded with piglet social interaction; therefore caution should be used when interpreting these results. The alternative farrowing systems described in the literature varied greatly from barren pens that only allowed the sow to turn-around; to more complex, enriched, and larger individual pens; to group housing systems that provided social interactions. In future research, it would be beneficial to determine which aspects of alternative farrowing systems (e.g. space allowance, enrichment, social contact) enhance piglet welfare.

V D. Piglet Physiology

V D 1. Cortisol and muscle pH. Few research studies have examined the effects of lactational housing system on the physiology of pigs post-weaning. Chaloupková et al. (2007b) investigated weaning stress among pigs reared in either standard or enriched (20% larger than standard crate, with straw) farrowing crates or individual farrowing pens (60% larger than standard crate, with straw). Cortisol secretion increased more after transport and weaning in pigs from standard farrowing crates compared with pigs from either enriched crates or individual pens. Moreover, the longissimus muscle pH was lower in pigs reared in enriched crates and tended to be lower in pigs reared in individual pens. Increased pre-slaughter stress results in lower meat pH. Thus, these findings are consistent with the concept that pigs reared in individual farrowing pens were less stressed than pigs from either standard or enriched crates.

V D 2. Piglet physiology summary. These findings are consistent with the concept that pigs reared in individual farrowing pens were less stressed than pigs from either standard or enriched crates. Repetition of the intriguing finding that lactational housing effects muscle pH at slaughter is needed as well as searching for similar responses to stressors at points between weaning and slaughter.

V E. Piglet Performance

V E 1. Feed intake and growth. There is evidence that lactational rearing environment can significantly influence post-weaning performance. Oostindjer et al. (2010) demonstrated that post-weaning growth rates and feed intakes were greater when piglets were reared in individual farrowing pens compared with farrowing crates. These authors suggested that the shared sow and piglet feeder in the individual pens enhanced social facilitation of feeding and increased early solid feed intake. Rantzer et al. (1995a, b; 1997) reported poorer feed conversion rates among piglets reared in lactational group pen systems than those reared in farrowing crates.

V E 2. Aggression and injuries. Compared with piglets reared in individual litter systems, piglets reared in lactational group housing systems demonstrate greater aggression and lesion scores before weaning, but after weaning piglets from individually housed systems show greater aggression and lesion scores (Rantzer et al., 1997; Wattanakul et al., 1997; O’Connell and Beattie 1999; Kutzer et al., 2009). O’Connell and Beattie (1999) hypothesized that piglets from enriched rearing environments developed social skills that allowed early establishment of a dominance hierarchy and therefore reduced aggression.

V E 3. Piglet performance summary. There is limited evidence to support an impact of lactational housing system on post-weaning piglet performance. Pigs reared in individual pens exhibited increased feed intake and growth rate compared with those reared in farrowing crates. However, other studies reported poor feed conversion in piglets reared in a group farrowing system compared to conventional crates. Post-weaning mixing aggression and injuries are commonly reduced among pigs reared in group farrowing systems compared with those reared in farrowing crates. Future research should replicate and extend the findings as to why some, but not all, forms of lactational environmental complexity positively impacts post-weaning piglet growth performance.

VI. Industry Relevance

In addition to the effect of lactational housing on the sow and piglets, other factors such as economics and management will influence their adoption by producers. Costs of alternative systems are rarely reported in the scientific literature and therefore will be only briefly addressed in this review. However, a more complete consideration of these factors can be found in Vosough et al., (2011); Guy et al., (2012); Baxter et al. (2012); and Seddon et al. (2013).

VI A. Economics. For commercial acceptance, piglet survival rates in alternative systems must be as favorable as for farrowing crates. Adopting alternative lactational housing systems has economic ramifications which include a capital investment and potentially costs associated with greater space allowance per sow and litter (Guy et al., 2012). Given the probable greater investment and operating costs of alternative systems, it would be economically advantageous if piglet survival or other performance measures surpassed those in farrowing crates. Therefore, the effects of the lactational housing system on piglet performance indicators up to and including slaughter may be relevant not only piglet welfare, but also cost analyses.

VI B. International commercial comparisons. Few research studies have been conducted on a commercial scale comparing alternative and conventional lactational housing systems. Commercial data are available from countries where farrowing crates are banned (Norway, Switzerland, and Sweden), but the data are not well reported in the peer-reviewed literature and may lack comparisons with other lactational housing systems. Baxter et al. (2012) summarized some of these examples. Individually penned sows from 39 Norwegian herds averaged 15.2% live-born mortality with a range from 5 to 24% (Andersen et al., 2007) and 99 Swiss farms averaged 11.8% live-born mortality (Weber et al., 2009). Using an extensive data set with 655 farms and 63,661 litters, Weber et al. (2007) demonstrated that on commercial farms in Switzerland, piglet mortality in individual pen housing was not different than in farrowing crates (pen = 17.2% from 18,824 litters; crates = 17.9% from 44,837 litters).

In contrast to what has been reported in Norway and Switzerland, in Denmark piglet mortality is greater in fully non-crated lactational housing systems on commercial farms, especially in the first 24 postpartum (Moustsen et al., 2013; Hales et al., 2014). Hales and colleagues (2014) reported 13.7% total mortality in the individual pens compared with 11.8% in the crates and Moustsen and colleagues (2013) reported 18.8 and 12.7%, respectively, in the first day after birth. However, using a hinged crate system, Moustsen et al. (2013) did not observe greater piglet mortality if the sows were crated for at least 4 d postpartum. Other factors such as litter size (Philips et al., 2014), sow parity, and management influence mortality and may interact with housing system. Hales et al. (2014) noted that conditions among the farms varied and highlighted the importance of management and pen design on performance.

Forty percent of the United Kingdom herds farrow in outdoor commercial systems (Guy et al., 2012) and their performance is recorded like that of indoor housing systems (BPEX, 2014). Although not analyzed statistically, the data suggests that outdoor systems consistently deliver favorable production; average data collected from industry databases over the last 13 years shows total mortality as 16.6% outdoor vs. 19.3% indoor and live-born mortality as 11.5% outdoor vs. 12.1% indoor (BPEX Pig Yearbooks 2001-2014). Consistent performance and sustainability in outdoor systems requires careful management, specific genotypes, and correct soil type. Because of the space requirements and soil type limitations, outdoor lactational housing systems are not a viable alternative to farrowing crates in many locations. Especially outdoor, but also other non-crated, lactational housing systems allow the differential expression of maternal behavior and rely heavily on appropriate maternal behavior. System designs that stimulate the expression of beneficial maternal behaviors (Baxter et al., 2011) and most likely genetic selection for maternal ability may aid the improvement of good maternal behavior expression in alternative lactational systems. However, more research needs to be conducted addressing on genetic selection of maternal behavior for alternative lactational housing systems.

VII. Final conclusions.

Our systematic review of the lactational housing literature was designed to investigate the impact of 4 different types of housing (conventional farrowing crates, hinged farrowing crates, individual farrowing pens, and group pen farrowing systems) on the welfare of sows and piglets.

The review encompasses the farrowing production phase, subdivided in to 3 time periods (nesting, farrowing and neonatal, and lactation) and the growth and finishing phases (post-weaning) and considers a variety of welfare outcomes that include behavior, physiology, and performance. Our goal was to identify knowledge gaps in the literature that would be particularly relevant to North American swine production. These gaps highlight areas for additional scientific investigation and promise new insight into our ability to design alternatives to the farrowing crate that best optimize the needs of the sow, the piglet, and the farmer.

The most consistent finding in our review process was the paucity of appropriate studies that compared alternative lactational housing systems to the conventional farrowing crate. In particular, very little useful information was gleaned regarding hinged farrowing crates or group based farrowing systems as most our findings focus on comparisons between conventional farrowing crates and individual farrowing pens. Furthermore, relatively little information is available on the impact of lactational housing type during the farrowing and post-weaning phases. And in most cases behavior comparisons between housing types are more plentiful than physiological or performance studies. However, the inherent variability in how the behavioral data was conceptualized, collected, and analyzed limited at our ability to draw meaningful conclusions from this type of study. Our understanding of sow and piglet behavior in farrowing systems might be advanced more readily if researchers were to agree on common behavioral measures to facilitate comparison of results between studies.

With regard to sow welfare during nesting and farrowing, most all indoor farrowing systems severely compromise the sow’s ability to pursue nest site selection and isolation from other pigs. In particular, farrowing crates also restrict the sow’s ability to engage in nest building behaviors. Failure by the sow to complete this behavior can have negative welfare consequences for the piglet as she may remain restless during the farrowing and early lactation phases putting the piglet at risk for being crushed and not getting sufficient quantities of colostrum due to prematurely interrupted early nursing bouts. Increased concentrations of cortisol during this period corroborate the behavior findings that farrowing crates can compromise sow welfare during this stage of lactational housing. Similar welfare concerns for the sow in farrowing crates are also apparent from the behavioral observations during the lactation phase. In particular, the decreased responsiveness to a piglet's vocalizations also promises to compromise the welfare of piglets reared in crates.

During parturition and early lactation, a better understanding of sow behavior and a more complete physiological stress profile would help to identify the extent of sow welfare compromise during lactation. Some of the relevant research questions that would help address the knowledge gaps are: "What are the consequences to the animal of not being able to pursue nest-site selection and isolation prior to farrowing?;" "Are there surrogate substrates that can be provided to sows to help fulfill a sow's need to nest build?;" and "How do different housing types shape sow behavior during parturition and early lactation?"

With regard to piglet welfare during the farrowing and neonatal period, very little is understood during this critical period of the animal's life. A better understanding of what regulates early nursing bouts and how it is impacted by housing type promises to ensure sufficient colostrum consumption and dramatically improve the likelihood of piglet survivability. The findings on piglet welfare during the lactation phase are somewhat equivocal, but the emerging body of evidence would suggest a pre-weaning mortality advantage for farrowing crates compared to individual farrowing pens. However, there are numerous studies that report no difference in mortality between these two types of lactational housing systems. These observations speaks to the need to better understand the causes of mortality, particularly in the 24 to 48 h post farrowing, between these two housing types. Another important area to understanding the success of these alternative lactational housing systems is the role of humans. Very little scientific work has addressed this critical resource and maybe an important determinant in how effectively alternative farrowing systems are implemented.

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TABLES

Table 1. Outcomes examined

Time period[1]	Sub-population	Outcomes		
		Behavior	Physiology	Performance
Nesting				
	Sow	substrate direc. rooting[2]	cortisol conc.[2]	body weight
		pen direc. rooting	prolactin conc.	feed intake
		lateral lying	progesterone conc.	
		sternal lying	oxytocin conc.	
		sitting	heart rate	
		standing		
		posture changes		
Farrowing and neonatal				
	Sow	inter-piglet birth interval	cortisol conc.	body weight
		cum. farrowing duration[2]	prolactin conc.	weight change
		nose piglet	progesterone conc.	feed intake
		substrate direc. rooting	oxytocin conc.	
		pen direc. rooting	heart rate	
		lateral lying		
		sternal lying		
		sitting		
		standing		
		posture changes		
	Piglet			total born
				born alive, no.[2]
				stillborn
				birth weight
Lactation				
	Sow	nose piglet	cortisol conc.	body weight
		substrate direc. rooting	prolactin conc.	weight change
		pen direc. rooting	progesterone conc.	feed intake
		lateral lying	oxytocin conc.	
		sternal lying	heart rate	
		sitting		
		standing		
		posture changes		
	Piglet	suckling		weaned, no.
		aggression		wean weight
		play		pre-wean gain
		belly-nosing		injury
				death, disease
				death, crushing

Time period[1]	Sub-population	Outcomes		
		Behavior	Physiology	Performance
Continued on next page				
				death, savaging
				liveborn mortality
				total mortality
Post-weaning				
	Sow		cortisol conc.	body weight
			progesterone conc.	weight change
			heart rate	feed intake
				WEI[2]
	Piglet	aggression	cortisol conc.	post-wean gain
		play	muscle acidity	injury
		belly-nosing		death, disease

[1]Nesting phase = 48 h prepartum until birth of the first pig; Farrowing and neonatal phase = first pig born until 3 d postpartum; Lactation phase = 4 d postpartum until weaning; Post-weaning phase = weaning until slaughter.
[2]direc.= directed; conc. = concentration; cum. = cumulative; no. = number; WEI = wean to estrus interval.

Table 2. Outcome categories reviewed

Time phase			
Nesting	Farrowing and neonatal	Lactation	Post-weaning
Sow behavior	Sow behavior	Sow behavior	[Sow behavior]
Sow physiology	Sow physiology	Sow physiology	[Sow physiology]
[Sow performance][1]	[Sow performance]	Sow performance	Sow performance
	Piglet behavior	Piglet behavior	Piglet behavior
	[Piglet physiology]	[Piglet physiology]	Piglet physiology
	Piglet performance	Piglet performance	Piglet performance

[1]Bracketed outcome categories are absent from the review because of gaps in the research literature.

Table 3. Articles that met the systematic analysis criteria.

Cite no.	First author and year	Farrowing housing types			Country
		Individual pen	Group. pen	Hinged crate	
1	Andersen et al., 2014	1	0	0	Denmark
2	Arey and Sancha, 1996	0	1	0	UK
3	Bates et al., 2003	0	1	0	USA
4	Biensen et al., 1996	1	0	0	USA
5	Blackshaw et al., 1994	1	0	0	Australia
6	Blackshaw et al., 1997	2	0	0	Australia
7	Bohnenkamp et al., 2013a	0	1	0	Germany
8	Bohnenkamp et al., 2013b	0	1	0	Germany
9	Bohnenkamp et al., 2013c	0	1	0	Germany
10	Bradshaw and Broom, 1999	1	0	0	UK
11	Chaloupková et al., 2007a	2	0	0	Czech R.
12	Chaloupková et al., 2007b	2	0	0	Czech R
13	Cronin et al., 1994	1	0	0	Australia
14	Cronin et al., 1996	1	0	0	Australia
15	Cronin et al., 2000	1	0	0	Australia
16	Damm et al., 2002	1	0	0	Denmark
17	Damm et al., 2003	1	0	0	Denmark
18	Devillers et al., 2008	1	0	0	Canada
19	Dybjær et al., 2001	0	1	0	Denmark
20	Farmer et al., 2006	1	0	0	Canada
21	Gilbert et al., 1996	1	0	0	UK
22	Gu et al., 2011	2	0	0	China
23	Hales et al., 2013	1	0	0	Denmark
24	Hartsock and Barczewski, 1997	2	0	0	US
25	Jarvis et al., 1997	1	0	0	UK
26	Jarvis et al., 1998	1	0	0	UK
27	Jarvis et al., 1999a	1	0	0	UK
28	Jarvis et al., 2000	1	0	0	UK
29	Jarvis et al., 2001	1	0	0	UK
30	Jarvis et al., 2002	1	0	0	UK
31	Jarvis et al., 2004	1	0	0	UK
32	Jarvis et al., 2005	1	0	0	UK

Cite no.	First author and year	Farrowing housing types			Country
		Individual pen	Group. pen	Hinged crate	
35	Continued on the next page				
33	Jarvis et al., 2006	1	0	0	UK
34	Korthals, 2003	0	1	0	US
35	Kutzer et al., 2009	1	1	0	Germany
36	Lawrence et al., 1994	1	0	0	UK
37	Lawrence et al., 1995	1	0	0	UK
38	Li and Wang, 2011	0	1	0	US
39	Li et al., 2012	0	1	0	US
40	Lou and Hurnik, 1994	1	0	0	Canada
41	Lou and Hurnik, 1998	2	0	0	Canada
42	Marchant et al., 2000	0	2	0	UK
43	Marchant-Forde, 2002	0	1	0	UK
44	McLean et al., 1998	1	0	0	UK
45	Melišová et al., 2014	1	0	0	Czech R
46	Moustsen et al., 2013	1	0	1	Denmark
47	Nowicki and Schwarz, 2010	0	1	0	Poland
48	Oliviero et al., 2008	1	0	0	Finland
49	Oliviero et al., 2010	1	0	0	Finland
50	Oostindjer et al., 2010	2	0	0	Netherlands
51	Oostindjer et al., 2011	2	0	0	Netherlands
52	Pedersen et al., 2011a	1	0	0	Denmark
53	Pedersen et al., 2011b	1	0	0	Denmark
54	Ringgenberg et al., 2012	1	0	0	Canada
55	Thodberg et al., 2002a	0	1	0	Denmark
56	Thodberg et al., 2002b	0	1	0	Denmark
57	Vasdal et al., 2009	1	0	0	Denmark
58	Verhovsek et al., 2007	1	0	1	Austria
59	Weber et al., 2007	1	0	0	Switzerland
60	Weng et al., 2009a	0	1	0	Taiwan
61	Weng et al., 2009b	0	1	0	Taiwan
62	Yun et al., 2013	1	0	0	Finland
63	Yun et al., 2013a	1	0	0	Finland
64	Yun et al., 2013b	1	0	0	Finland

Cite no.	First author and year	Farrowing housing types			Country
		Individual pen	Group. pen	Hinged crate	
65	Yun et al., 2013c	1	0	0	Finland

Table 4. Examples of meta-analysis estimates of mean differences from 3 different outcomes comparing individual pens and farrowing crates.

Measure	n[1]	MD[2]	CI[3]	MD *P*-value[4]	Q[5]	I-sqrd[6]	I-sqrd *P*-value[7]	Max wt[8]	Fig. ref.
Cortisol[9]	15	-13.2	-15.4 to -11.0	< 0.0001	11.59	0.0	0.638	29.3%	1
Prolactin[10]	12	-0.07	-11.3 to 1.1	0.9045	25.43	56.7	0.008	14.6%	2
Born alive[11]	9	0.002	-0.04 to 0.04	0.9283	6.95	0.0	0.542	99.0%	3

[1]n = number of studies used in the meta-analysis.
[2]MD = mean difference of measure between individual pens and farrowing crates.
[3]CI = confidence interval around the mean difference.
[4]MD *P*-value = significance of the mean difference using a random effects model.
[5]Q = measure of heterogeneity in data.
[6]I-sqrd = scaled measure of heterogeneity in data.
[7]I-sqrd *P*-value = significance of heterogeneity in data.
[8]Max wt = maximum weighting of an individual study using inverse variance weighting.
[9]Cortisol concentrations measured from 48 h prepartum to 4 h postpartum (ng/mL).
[10]Prolactin concentrations measured from 48 h prepartum to 4 h postpartum (ng/mL).
[11]Number of piglets born alive among litters that farrowed in either individual pens or crates.

FIGURES

Study	Experimental Total	Experimental Mean	Experimental SD	Control Total	Control Mean	Control SD	MD	95%-CI	W(random)
Jarvis 1997	16	26.36700	13.304000	15	40.89400	21.010935	-14.53	[-27.00; -2.05]	3.1%
Jarvis 2002	9	6.37600	13.113000	8	14.31900	8.946315	-7.94	[-18.52; 2.63]	4.3%
Lawrence 1994	17	22.30500	6.217643	16	34.21200	11.024000	-11.91	[-18.06; -5.75]	12.8%
Jarvis 1997	16	37.33500	15.868000	15	60.35600	27.110883	-23.02	[-38.79; -7.25]	2.0%
Lawrence 1994	17	27.97400	3.859227	16	42.89400	10.616000	-14.92	[-20.44; -9.40]	16.0%
Jarvis 1997	48	39.09733	18.026832	45	49.15633	22.327891	-10.06	[-18.34; -1.78]	7.1%
Jarvis 1998	16	39.00650	17.880798	14	49.97650	21.467443	-10.97	[-25.23; 3.29]	2.4%
Jarvis 2002	9	14.07500	5.325000	8	25.52700	8.725698	-11.45	[-18.43; -4.48]	10.0%
Lawrence 1994	34	26.20400	6.119701	32	38.47450	10.140369	-12.27	[-16.34; -8.20]	29.3%
Jarvis 1997	16	31.88900	12.120000	15	40.60000	22.300638	-8.71	[-21.46; 4.04]	3.0%
Jarvis 1998	8	49.57000	27.964659	7	57.69500	31.534710	-8.12	[-38.48; 22.23]	0.5%
Gilbert 1996	17	119.45400	20.829930	16	158.14900	47.948000	-38.70	[-64.19; -13.20]	0.7%
Lawrence 1994	17	30.72800	7.722577	16	50.30400	14.352000	-19.58	[-27.51; -11.64]	7.7%
Jarvis 2004	9	48.85900	29.397000	8	73.69100	34.170228	-24.83	[-55.32; 5.66]	0.5%
Jarvis 1999	6	36.41200	18.892914	6	51.65800	35.368182	-15.25	[-47.33; 16.84]	0.5%
Random effects model	**255**			**237**			**-13.18**	**[-15.39; -10.98]**	**100%**

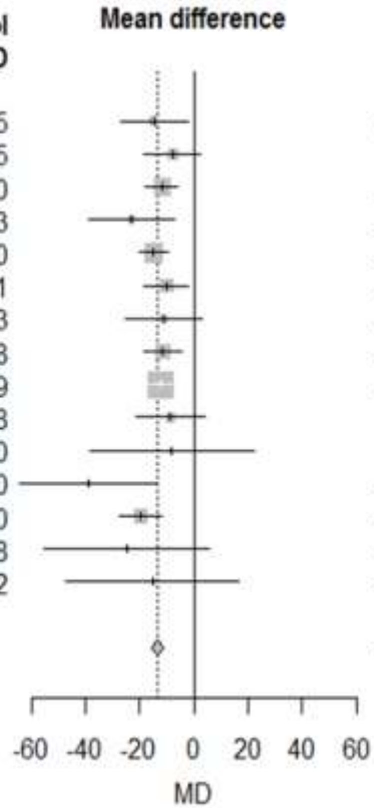

Figure 1. Comparison of cortisol concentrations of sows housed in either individual pens or farrowing crates.

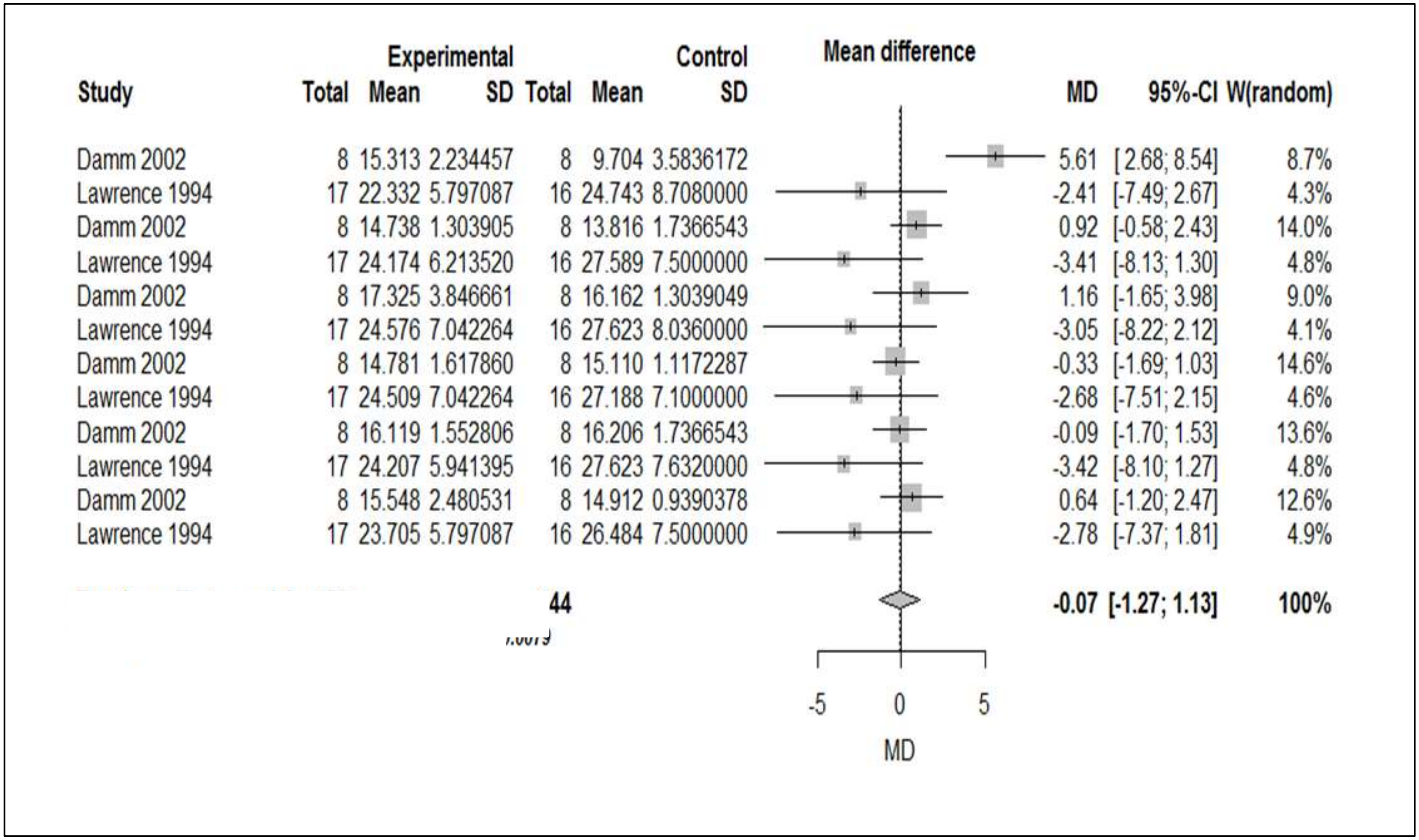

Figure 2. Comparison of prolactin concentrations of sows housed in either individual pens or farrowing crates.

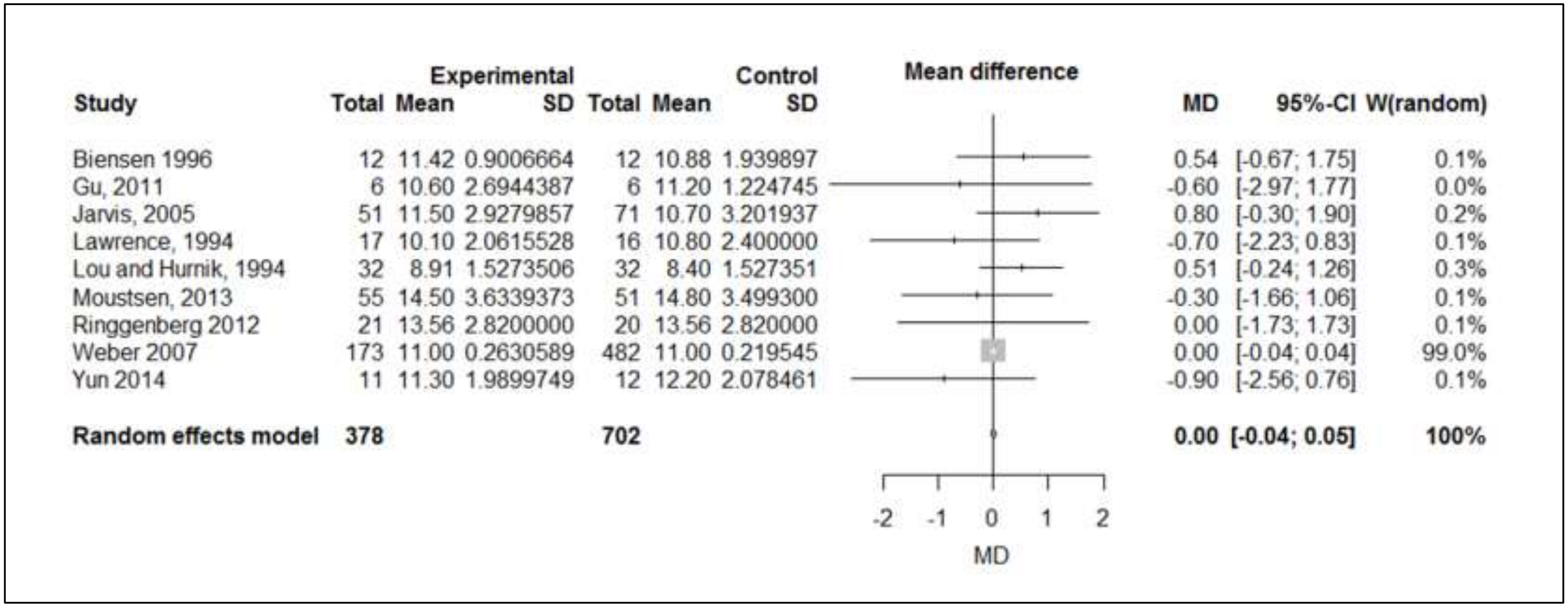

Figure 3. Comparison of the number of piglets born alive to sows housed in either individual pens or farrowing crates.

APPENDIX A

Database search terms

TS=((sow* OR litter* OR swine OR pig* OR piglet* OR gilt*) AND (farrow* OR lactation* OR parturition OR lactating OR nursing* OR birth* OR rearing) AND (housing OR accommodation* OR pen OR crate OR stall OR penned OR crated OR environment* OR husbandry OR management OR pens OR crates OR housed) NOT (dog* OR lizard* OR ewe* OR kid* OR sheep OR lamb* OR rat* OR mouse OR mice OR rodent* OR guinea OR cavies OR goat* OR rabbit* OR cat* OR fish* OR beef* OR dairy* OR cow* OR hen* OR broiler* OR layer* OR pigment* OR insect* OR poultry))

APPENDIX B

Relevance tool

1. Was this article published in English in a peer-reviewed journal after 1989?[1] Y N

2. Does this abstract describe primary research? Y N

3. Does this abstract investigate any of the following? Circle all that apply.

    a. Performance, physiology, or behavior outcomes for sows housed in both alternative and conventional farrowing systems

    b. Performance, physiology, or behavior outcomes for piglets housed in both alternative and conventional farrowing systems

[1]The date criterion was later changed to after 1993 to better reflect the transition to modern swine genetics.

APPENDIX C

Expert panel participant list

Participant	Affiliation
Emma M. Baxter	SRUC
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