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REVIEWS

REVIEW: Compilation of the Scientific Literature Comparing Housing Systems for Gestating Sows and Gilts Using Measures of Physiology, Behavior, Performance, and Health[1]

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Abstract

*The objective of this review was two-fold. First, a series of meta-analyses (analyses of treatment effects across studies) were performed on available data from scientific literature to determine whether sow behavior, performance, or physiology differed for sows in group pens or individual stalls. Second, research publications in areas of performance and health, physiology, and behavior of pregnant gilts and sows in studies that directly compared gestation sow housing systems were summarized. Common systems were stalls, tethers, and various types of group housing systems. Results of meta-analyses showed that the average levels of productivity, oral-nasal-facial behaviors (**ONF**), and blood cortisol were statistically similar for sows in group pens and stalls. For the review, in some studies, circulating cortisol concentrations were greater among gestating females kept in tethers compared with other systems; however, overall cortisol was not altered by housing system. Immune parameters were largely not influenced by housing system. Housing system did not alter heart rate. Gestation housing system may influence sow behavior including stereotypic ONF, postural locomotory, feeding behaviors, or social behaviors. Overall, total ONF behaviors were comparable between gestation sow housing systems. However, tethered and stalled sows exhibited more stereotypic ONF compared with sows in group or outdoor systems. Compared with group housing, individually confining sows during gestation resulted in postural and movement restrictions. Stall size and design can impact postural adjustments and inter-stall aggression of individually housed sows. Inconsistent performance and health results were found among sow housing studies. Sows in stalls consistently had equal or greater reproductive performance compared with sows in other systems. Farrowing rate for sows in individual stalls was equal to or superior to sows in other systems. Farrowing rate was clearly superior among sows in stalls compared with group systems, where dynamic social groups were employed. However, tethered sows may have reduced litter size and increased piglet birth weight.*

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*Sows in group housing systems, particularly electronic sow feeder (**ESF**) systems, had injury scores greater than sows in either stalls or tethers. Gestation housing system (individual vs group) may impact sow welfare in the farrowing area (using stalls or pens). In conclusion, although individual studies found significant housing system effects, subjected to the overall evidence from adequately designed studies meta-analyses revealed that gestation stalls (non-tethered) or well-managed pens generally (but not in all cases) produced similar states of welfare for pregnant gilts or sows in terms of physiology, behavior, performance, and health. More research is needed to develop and evaluate the efficacy of sow housing systems, including studies that directly compare sow housing systems using a multi-disciplinary approach.*

(Key Words: Environment, Housing Systems, Sow, Welfare.)

Introduction

Gestation sow housing methods are a contemporary animal welfare issue particularly in Europe and North America. Selected European countries and the European Union have banned or are phasing out use of stalls and tethers for gestating sows. Some US markets seek pork from systems that do not individually house sows. The scientific data that might support animal welfare positions are widespread and multidisciplinary. The broad objective of this paper was to review and summarize the body of scientific information on gestation sow housing systems. The specific objective of this review was to summarize research publications in areas of performance, health, physiology, and behavior of sows in studies that directly compared sow gestation housing systems.

Methods

Scientific literature was gathered from both electronic databases (primarily Agricola [USDA-National Agricultural Library, Beltsville, MD], BIOSIS, Current Contents [ISI, Philadelphia, PA]) and from sources known to the authors. The period of literature covered by the electronic databases in this review was from 1970 through September 2002. Earlier literature was gathered from non-electronic sources by the authors. The results of the literature review are reported in three sections: 1) physiology, 2) behavior and 3) performance and health.

When attempting to compare gestation housing systems, there can be a number of important variables relating to sow housing. For example, group housing systems often use bedding; sows in stalls are often on slatted flooring. Other system components are important in the proper care of gilts and sows, but these components are not reviewed here. Such components include, but are not limited to, genotype, infectious disease, number of animals per pen, floor type, space allowance, stable *vs* dynamic social groups, pen shape, bedding, feed and water schedule, delivery system, ventilation, waste system, and level of stockmanship.

Because there are a number of potential confounding variables when trying to compare housing effects between different experiments, only experiments that included direct comparisons of gestation housing systems were directly discussed in this review. All relevant studies published in refereed journals were included in the meta-analyses. Economic, human perception-based, and model-building studies were not included.

Gestation sow housing system studies are difficult to interpret in part because obtaining clear replication is often difficult; this is particularly true when comparing individual sow housing systems to group housing systems. When sows are housed in a social group, the experimental unit is clearly the pen or group of sows. The group will have a certain mean and within-pen variation, but it is the variation among pens that is important to compare with other housing systems because social status and individual pen social dynamics play major roles within each pen. The pen is the experimental unit for data from pens of animals rather than the individual animal. Papers were not included for discussion if the experimental unit was not replicated. However, when a single group pen [ex., ESF (electronic sow feeders)] was reported in a study, the data from these papers were included in the meta-analyses.

A meta-analysis was performed by extracting available data from scientific papers. In the meta-analysis, the mean value for a treatment within each paper was the experimental unit. In this case, if values from an unreplicated pen were in the paper, it was included in the meta-analysis because each study represented a single observation.

Data were present from 35 refereed journal articles that compared sow housing systems. A criterion was set that, for a given measure, three papers (with extractable data) were required to include that housing system in the meta-analyses. Only data from pen and stall systems qualified. Systems that had only one or two (but not three) papers included the tether, outdoor, trickle-feeding, and ESF systems. Measures that met the criteria included farrowing rate, pigs born alive, stillborn pigs, piglet BW, oral-nasal-facial (ONF) behaviors, stereotyped bar biting, and blood cortisol concentrations. Several papers reported measures, but in graphical form, and extraction of a precise number was not possible.

The analyses were performed in four ways. The full data set was analyzed using both GLM and MIXED analyses. Second, a reduced, balanced data set was analyzed by both methods. In the balanced data set, papers were only included if they had, in the same paper for pens and stalled sows, measured farrowing rate, pigs born alive, stillborn pigs, and(or) piglet BW. The models were run with two independent variables:

housing system and study (unique paper) or simply with housing system.

Welfare measurements for gilts and sows are not uniformly agreed upon by the scientists in the international community or by the commercial pig industry. The authors did not attempt to create a new definition of the term animal welfare. Rather, the authors examined measures commonly considered when assessing welfare including measures of performance and health, behavior, and physiology for gilts and sows in each gestation housing system. Based on common use around the world and the availability of scientific literature, the authors considered the following gestation sow housing system categories: stall (also called crate), tether (including neck and girth varieties), group pens indoors, and group paddocks outdoors. Stalls and tethers are systems of individual housing of sows that do not allow turning around; these systems allow only minimal social interactions among neighbors. Group pens might include a variety of feeding systems (e.g., floor feeding, drop feeding, or trickle feeding) and flooring types (bedding or solid floor). The authors gave consideration to some system components (e.g., ESF, trickle feeding, and dynamic social groups, where controlled data were available. Among these common individual and group sow housing systems, the differences in system components (e.g., space, bedding, floor type, feeding system) may make interpretation among gestation housing systems and system components a challenge. Other less common sow housing systems are used on commercial farms, but the authors concluded that there was insufficient scientific literature that directly compared systems to justify incorporation of these studies (and housing systems) in the review.

Other reviews or models have been published on the welfare of pigs based on scientific studies or expert opinion (SVC, 1997; Bracke et al., 1999; Barnett et al., 2001; Bracke et al., 2002; Meunier-Salaün et al., 2002). The present review differs in that our focus is on research that directly compared housing systems for only the pregnant gilt or sow. If a paper did not examine pregnant gilts or sows (e.g., non-pregnant pig stress models) and if it did not directly compare more than one housing system, then the work was not included. A few review articles or field studies were also included for completeness.

Results and Discussion

Gestation Housing Effects and Meta-Analysis. Results from the meta-analyses are given in Table 1. Two of the analyses are presented in Table 1, including the full data set and the balanced dataset. In both cases, no measures were significantly (P>0.05) influenced by sow housing system. For measures of farrowing rate, ONF, and bar biting (one component of ONF), all but one paper had very similar mean values. For these three measures, the large SE was attributed to a single paper. Absent the single non-consistent paper, the means were very close, and the SE was substantially less.

Sows housed in pens and stalls had similar mean values across all measures with each analysis that was used. The means were very similar for sows in pens and stalls from both a biological and statistical perspective.

The results (P values and least squares means) from the GLM and MIXED analyses were identical when the same model was entered. The meta-analysis demonstrated that sows housed in stalls and pens had similar levels of selected measures of productivity (reproduction), glucocorticoid, and behavior. The meta-analysis results confirmed the within-study, generally consistent findings that sow biological measures were similar for sows in group pens and individual stalls. Considering alternative systems, such as trickle-feeding, ESF, and outdoor systems, fewer data were available, but the general trends in biological measures were similar for sows in stalls and pens. The issue of sow welfare in alternative housing systems should be revisited when more data are available.

Others may want to conduct further analyses or add data over time and then re-analyze the data set. The full dataset is available from the corresponding author by electronic mail.

Gestation Housing Effects on Physiology Measures. Stress impacts several physiological systems including the nervous, endocrine, immune, cardiovascular, gastrointestinal, and renal systems. Early research indicated that animals had a general adaptation to stress known as the general adaptation syndrome (Selye, 1976). Stressed animals exhibit elevated glucocorticoid concentrations, gastric ulcers, cardiovascular effects, and immunosuppression. Each of these is considered important because they indicate a prepathologic state in the animal (McGlone, 1993; Moberg, 2000).

Today most authors agree that some or all of these effects may be observed in stressed animals. One central concept is that corticotropin-releasing factor (**CRF**) is a common mediator of the observed effects of stress. Elevated CRF directly or indirectly causes the release of ACTH, opioids, catecholamines, or glucocorticoids. Changes in these hormones may lead to elevated heart rate and blood pressure, as well as immunosuppression (Dunn and Berridge, 1990). Many questions remain about how the environment impinges upon the nervous, endocrine, and immune systems and the interaction among these systems. Most studies have focused on the effects of acute rather than chronic stress on these systems, and researchers have used endocrine and immune measures more than other physiological measures to compare sow housing systems. It appears that the physiological data from a number of studies indicate the welfare of sows in stalls is equal to, or better than, that

TABLE 1. Summary of 35 papers comparing pens and stalls for gestating sows.

	All studies[a]			Studies with both systems[c]		
Item	Pen	Stall	P	Pen	Stall	P
Farrowing rate						
%	75.9 ± 2.9	83.3 ± 2.3	0.09	75.9 ± 3.6	80.6 ± 3.6	0.45
N[b]	3	5		3	3	
Piglets born alive per litter						
%	9.9 ± 0.27	9.9 ± 0.27	0.87	9.9 ± 0.33	9.8 ± 0.33	0.63
N	14	15		11	11	
Stillborn pigs per litter						
%	0.73 ± 0.08	0.58 ± 0.09	0.26	0.71 ± 0.10	0.63 ± 0.10	0.55
N	11	10		9	9	
Total pigs born per litter						
%	10.8 ± 0.32	10.5 ± 0.36	0.53	10.8 ± 0.38	10.5 ± 0.38	0.58
N	11	10		9	9	
Piglet birth weight						
kg	1.46 ± 0.03	1.43 ± 0.03	0.42	1.44 ± 0.03	1.44 ± 0.03	0.70
N	7	8		7	7	
ONF[d] behaviors						
%	15.2 ± 17.8	32.7 ± 13.2	0.45			
N	5	9				
Stereotyped bar biting						
%	7.7 ± 46.8	55.9 ± 41.8	0.47			
N	4	5				
Cortisol						
%	10.4 ± 6.3	16.8 ± 7.7	0.54			
N	6	4				

[a]All studies include papers that did not necessarily have both systems (pen or stalls).

[b]N refers to the number of papers that reported a given measure. Raw data are available from the corresponding author for additional analyses.

[c]These studies had measures for both penned and stalled sows in each study.

[d]ONF = Oral, nasal, and facial.

of sows in tethers or groups. In this review, we considered these indicators to evaluate the impact of each housing system on sow welfare.

Cortisol Concentrations. The classic hallmark of an acute stress response is an increase in circulating cortisol concentrations (Selye, 1976). Cortisol has also been the most common physiological parameter used to measure farm animal welfare (Terlouw et al., 1997). Cortisol is relatively easy to measure, but its measurement suffers from diurnal variations and sample collection artifacts. Elevated blood cortisol is clearly a sensitive measure of acute stress, but its use as a measure of long-term welfare is arguable, especially where values do not differ between housing systems.

Scientific literature on the impact of housing systems on gestating sows has reported consistently less circulating cortisol concentrations among females placed in stalls or individual pens (large enough to allow turning around) compared with females kept in tether systems (Barnett et al., 1985, 1987, 1989; Janssens et al., 1995a, b). Circulating or urinary cortisol concentrations were similar when sows were housed in stalls or groups with three to six pigs per pen (von Borell et al., 1992; Tsuma et al., 1996; Pol et al., 2002). Certain tether stall designs may cause an elevation in cortisol. Cortisol concentrations were greater when sows were kept in tether stalls with horizontal bars where neighbors could easily express aggression against each other compared with sows in tether stalls with vertical bars where neighbor aggression was prevented (Barnett et al., 1991). In addition, circulating cortisol concentrations were similar for pregnant sows (one sample collected between 0800 to 0900 h on d –4, 3, 17, 38, and 66 of gestation) housed in stalls compared with those in ESF groups with the exception of the sample collected at 17 d. For that collection, stalled young sows showed elevated cortisol concentrations compared with young sows in the ESF system (Jensen et al., 1995). In a separate study, for sows sampled on d 3, 38, and 66, stalled and ESF-housed sows had similar cortisol concentrations (Jensen et al., 1996). Cortisol concentrations were also influenced by parameters other than housing system. Time of day in which blood samples were taken had an effect on cortisol concentrations, but the housing system did not affect the diurnal profile of cortisol concentration. Janssens et al. (1995b) reported that tethered sows had greater cortisol concentrations at 1800 h relative to sows kept in stalls. However, when samples were collected at 1000 h, there were no differences in cortisol concentrations for sows kept in either stalls or tethers (Janssens et al.,1995b).

ACTH and CRF Challenge or Suppression. Adrenal responses to stimulation or suppression have been used as a potential indicator of a chronic stressful environment. Adrenal response may reveal housing system effects when basal cortisol is not elevated. In most studies that compared group housing and tethering, basal cortisol concentrations and cortisol concentrations after ACTH challenge were lower for group-housed sows than for tethered sows (Barnett et al., 1985, 1989, 1991). Other studies comparing sows kept in groups or stalls reported little or no differences in basal cortisol or cortisol secretion after an injection of dexamethasone or ACTH (Barnett et al., 1982; von Borell et al., 1992; Mendl et al., 1993; Jensen et al., 1996). Cortisol-to-ACTH ratio was two-fold higher for sows housed with tethers following an intravenous injection of CRF than for sows housed in stalls (Janssens et al., 1995a).

Other Physiological Measures. Elevated blood glucose may be associated with elevated blood glucocorticoid concentrations during a stressful experience. Barnett et al. (1985, 1989) found greater plasma glucose and lesser plasma urea (a consequence of elevated glucocorticoid concentrations) for gilts kept indoors in tethers than for gilts kept indoors in groups. Elevated glucose concentrations were also found among tethered gilts housed indoors compared with gilts housed outdoors in groups (Barnett et al., 1985). Plasma glucose, urea, and total protein concentrations were similar for gilts kept in stalls or indoors in groups. Stress and central release of CRF may cause activation of the opioid system or release of endogenous opioids, which has been used as an indicator of animal welfare among sows in different housing systems (Zanella et al., 1996).

Immune Measures. No studies to date have shown an overall effect of housing system on the immune function of gestating sows kept in various housing systems. Antibody production and neutrophil-to-lymphocyte ratio were not different between females kept in stalls or individual pens compared with those kept in groups or in tether stalls (von Borell et al., 1992; McGlone et al., 1994; Broom et al., 1995). Where sows were evaluated through two pregnancies, there were no differences between girth-tethered and stall-housed sows in natural killer cell activity, antibody response to sheep red blood cell antigens, or differential leukocyte counts (McGlone et al., 1994). In general, gestating sow housing systems did not influence immune measures.

Rearing Environment Impact on Physiology. The environment in which gilts are reared prior to breeding could have an effect on their ability to adapt or cope in a particular gestation housing environment. Two studies compared fertility in females reared in pens indoors or outdoors. Gilts kept on dirt lots had more corpora lutea than did gilts kept in neck-tethers or group-housed indoors (Jensen et al., 1970). Rampacek et al. (1984) found that gilts kept outdoors had greater luteinizing hormone concentrations than did gilts raised indoors in individual pens. These authors did not find differences in progesterone concentrations for sows in the two environments. Basal cortisol concentrations were not different between the two groups, but circulating cortisol increased more rapidly and to a greater extent following an ACTH challenge in gilts kept outside (Rampacek et al., 1984). These early studies indicate that gilt pubertal development may be suppressed by indoor *vs* outdoor rearing.

Gilts initially kept in groups then moved to a tether housing system had greater circulating cortisol concentrations through three estrous cycles after tethering (Janssens et al., 1995a). By contrast, cortisol concentrations remained unaltered among the gilts that were kept in a group housing system for the entire experimental period. In a more recent study, gilts were either reared indoors or outdoors during development and were moved into individual gestation stalls in an indoor gestation unit (McGlone and Fullwood, 2001). Rearing environment did not influence immune parameters or endocrine measures. In contrast to moving from outdoors to neck tethers (Jensen et al., 1970), moving from outdoors to indoor gestation pens or stalls did not inhibit litter size (McGlone and Fullwood, 2001).

The social environment may also influence endocrine responses during development. Barnett et al. (1985) reported that tethered gilts had greater (2.23 ng/mL) free cortisol concentrations than gilts housed in stalls (1.46 ng/mL). Coping ability, as determined by behavioral resistance during a back test (piglets are placed on their back, and their responses are noted), may determine a gilt's ability to adapt to an individual housing system such as the stall (Ruis et al., 2001). "Low-resistant" pigs were defined as pigs that make two or fewer escape attempts when restrained on their back. Gilts that were considered to be low resistant had greater blood cortisol concentrations than did high-resistant gilts when housed individually in pens. Body temperature was greater in high-resistant gilts than in low-resistant gilts. A shift in leukocyte subsets only occurred in high-resistant gilts during isolation. Gilts kept in groups of eight had heavier adrenal and pituitary glands, brains, and uteri and ovulated earlier than did gilts kept in groups of 16 per pen (Rahe et al., 1987). Thus, gilt or sow group size may influence physiological measures.

Summary of Physiological Measures. The availability of physiological data from the scientific literature is rather limited for gestating pigs kept in different housing environments. Data are especially limited on the effects of sows kept in groups in different environments. The majority of the studies used cortisol as their primary physiological measurements; however, cortisol was not consistently affected by housing environment. In general, tethered sows have increased basal cortisol concentrations and may have a greater response to exogenous ACTH than sows kept in stalls or groups. The impact of housing on the sow endocrine system was not enough to affect immune responses. Nonetheless, it was apparent that the design of the stall and the expression of the social hierarchy within the group are important variables affecting the physiological response of sows to their gestation housing system. For instance, when an appropriate partition was positioned between tethered sows, plasma cortisol concentrations were reduced to concentrations consistent with group-housed pigs (Barnett et al., 1991). Thus, relatively minor adjustments to the environment may have effects on the animal's physiological response to the system.

Overall, physiological changes were only observed when one or more relatively severe stressors challenged the sows. Studies often used diverse gestation sow housing systems but reported similar physiological values. Also, for assessment of welfare, the authors believe it is important to link physiologic change to other measures such as health, longevity, performance, or behavior.

Gaps in Knowledge of Comparative Gestation Housing Systems and Physiology. Numerous gaps were identified in the literature concerning the impact of gestating sow housing systems on physiology. Studies need to be designed to evaluate the impact of housing systems on the physiological parameters of the sow such as the nervous, endocrine, and immune systems. No study considered more than a few functional aspects of the immune response.

The immune system may not be altered in response to increases in circulating cortisol, but may be altered by other endocrine factors not measured in the studies that were reviewed (such as catecholamines). Also, sample collection time of day or stages of gestation should be considered in the design of studies because these factors may impact endocrine and immune responses. Effects of sow housing systems on cardiovascular physiology are lacking, and this system may be an important physiological parameter relevant to sow longevity and welfare.

Gestation Housing Effects on Behavioral Measures. Sow behavior differs from one system to another, but quite often the non-housing components of a system are responsible for the behavior adopted by sows. Measurements used to assess the effect of sow housing on behavior range from analyzing detailed sequences of behavior to quantifying total time budgets (time that the sow is engaged in a specific behavior). Time budgets can be expressed in units of time or as a percentage. Sow behaviors such as ONF behaviors have been recorded from just a few hours per day to entire 24-h periods. Main results from papers that compared two replicated gestation sow housing systems are reported by the following behavioral categories: ONF, postural and locomotory, and social behavior.

ONF Behaviors. A subset of ONF behaviors has sometimes been called stereotypies. Stereotypies are repetitive, relatively invariable sequences of non-functional behaviors that potentially indicate reduced welfare (Fraser and Broom, 1990; Mason, 1993). Oral-nasal-facial behaviors may include stereotypies (stereotyped behaviors that serve no apparent function) but may also include functional behaviors such as feeding, drinking, and rooting, implying different underlying motivations for ONF behaviors. Although some studies reported total ONF behaviors, other studies looked specifically at stereotypical ONF behaviors, making comparison of housing systems based on ONF behavior difficult. To evaluate the adaptation of sows to different housing systems, investigators have quantified the duration and frequency of non-feeding ONF activities. Dailey and McGlone (1997a) found no differences in ONF behavior measured over 24 h in three systems (outdoors on soil, outdoors on pasture, or in gestation stalls), which differed in the space allowance per sow, substrate availability, ability to perform social behaviors and thermoregulation. This result suggests that gestating sows may be highly motivated to show ONF behaviors regardless of the housing system.

Vieuille-Thomas et al. (1995) observed sows housed in tethers, stalls, and groups for the occurrence of stereotypic behaviors. Those researchers defined stereotypic behaviors as repeated movements, oral activities without obvious finality, rooting, and nosing as sterotypies. Sows in all housing systems were continuously observed for 1 h starting from the beginning of morning feed distribution. Tethered and stalled sows had greater levels of stereotypic behavior (94 and 89%, respectively) while grouped-housed sows engaged in less (66%) stereotypic behavior. Den Hartog et al. (1993) did not find a difference in bar biting between girth-tethered sows and stalled sows. However, McGlone et al. (1994) found that tethered sows showed significantly fewer ONF behaviors than did sows in stalls. Most studies that compared sow behavior when in tethers and stalls used stalls with front bars and tethers without front bars (Den Hartog et al., 1993; McGlone et al., 1994; Vieuille-Thomas et al., 1995). Substrate availability, such as bars, may influence performance of ONF behaviors. Animals within the housing systems reviewed expressed differences in sow ONF behaviors, but their biological significance and causation remain unclear.

Animals within the same housing systems may vary in average frequency of stereotypies performed, as the propensity to develop stereotypic behavior has been shown to be related to age and parity of the sow (von Borell and Hurnik, 1991). Stereotypies appear to be related more to individual characteristics of sows and less to housing systems. A high frequency of these behaviors was associated with sows presenting the following traits: standing still 1 h after food distribution, having a low body fat score, and keeping an alert, upright body posture when lying (Vieuille-Thomas et al., 1995). Some of these sow characteristics may indicate a problem in adaptation to the conditions for an individual sow. Sows showing these behaviors were found in both individual and group systems.

The comparative study by Blackshaw and McVeigh (1984) analyzing group-housed sows, stalled sows, and neck-tethered sows reported that group-housed sows showed fewer pre-feeding ONF behaviors and no post-feeding stereotypic behavior. Backus et al. (1997) found no differences in the level of post-feeding oral activities among three types of housing systems for sows fed twice a day in individual stalls, free- access stalls, and trickle-feeding group housing. Cariolet et al. (1997) showed also that sows performed post-feeding oral activities 59% of the time when tethered, which did not differ from other sow housing systems.

Dailey and McGlone (1997a) studied indoor and outdoor gilt behavior. Indoor gilts were less active than outdoor gilts and showed more sitting behavior (possibly a sign of boredom). The ONF behaviors in the form of chewing occurred more often among outdoor gilts than among indoor gilts, but chewing was not associated with rooting. Rooting occurred at similar levels for indoor- and outdoor-kept gilts.

In another study, Dailey and McGlone (1997b) also compared the behavior of individually housed sows in three systems: indoor gestation stalls, penned outdoors (30 m^2 per sow) on soil, and penned outdoors on pasture. Sows in each treatment performed similar frequencies of total ONF behaviors (including stereotypies and non-stereotypies). Sows kept on pasture chewed grass (chewing was defined as jaw movement with contact with any substrate, which may or may not be considered functional feeding behavior). Sows kept on soil chewed rocks and soil and sham chewed (chewing nothing). Sows kept in stalls chewed the bars of their stall. Sows appear highly motivated to express ONF behaviors regardless of the environment. During the 24-h day, there were similar overall durations of stereotyped and non-stereotyped ONF behaviors for the three treatments. Nevertheless, outdoor sows had a more pronounced bi-phasic activity pattern (two behavioral peaks during a 24-h cycle) than indoor-housed gilts (Tober, 1996; Dailey and McGlone, 1997b; Buckner et al., 1998), which may indicate how the housing system impacts daily behavioral rhythms.

In conclusion, for ONF behaviors, sows in tethers may have greater or lesser ONF behaviors, depending on experimental conditions. However, one can only conclude from the variety of individual study findings and our meta-analysis across studies (Table 1) that sows in stalls or groups show similar ONF behaviors and that the causes of ONF are likely to be factors other than housing system. Based on the meta-analysis (Table 1), ONF and stereotyped bar biting are not measures that distinguish sow welfare across housing systems.

Postural and Locomotory Behaviors. In stalls or tethers, the most important constraint on behavior is limitation of movement. Standing, lying, and measures of posture may relate to the comfort sows experience. In stalls, the sow can move within the limits of the bars or fences. One stalled sow can influence a neighboring sow's behaviors. Bergeron et al. (1996) found a high correlation ($r^2 = 0.80$ to 0.95) for behaviors (lying, sitting, standing, ONF behaviors) between neighboring gilts in either standard gestation stalls or turn-around stalls (stalls of minimal size that permitted turning). Gilts in the turn-around stalls stood more frequently and had greater rates of nosing behavior (ONF) toward stall bars compared with gilts in stalls. Gilts unable to turn around did not show more ONF behaviors, which suggests that ONF behaviors are not "caused" by the lack of ability to turn around in a stall.

Housing system during gestation may influence the behavior of sows while they are in the farrowing area. Boyle et al. (2000) compared behavior of gilts (during the first hour in the farrowing stall) that were previously housed in stalls or group-housed in bedded or unbedded pens. Those researchers reported that group-kept, bedded gilts were more active; stall-kept gilts engaged in more grunts. At d 8, stall-housed gilts showed significantly fewer postural changes than did gilts in groups, indicating that gilts previously housed in groups had a more difficult time adapting to the farrowing stall. Furthermore, fewer postural changes by the gilt may be an advantageous behavior to help lessen the incidence of pre-weaning piglet mortality.

Comparing multiparous sows from group housing *vs* stall systems, Boyle et al. (2002) found that on the first day after entering the farrowing stall, sows kept in gestation stalls made significantly more attempts to lie down, spent more time inactive and less time lying laterally than sows from groups. On d 10 of lactation, sows group-housed during gestation had more postural changes, more ventral and lateral lying and dog sitting behaviors. There was an improved maneuvering ability of sows group-housed during gestation *vs* stall-housed sows. However, previously group-housed sows were more restless during parturition and during early lactation, suggesting that group gestation housing may have a negative influence on sow welfare when these sows are placed in farrowing stalls. Restless sow behavior at the time of parturition and into lactation may result in an increased number of stillborn piglets, an increased risk of pre-weaning mortality (Weary et al., 1996) and possibly a disruption in the nursing cycle between sow and litter (Spinka et al., 1997).

Several studies reported the relationship between stall size and the postural and motor activity in gestating sows. Anil et al. (2002) measured sow length, breadth, and height as well as stall length (excluding feeder) and used the relative stall-to-sow measurements to study the effect of gestation stall size on postural behaviors including standing, sitting, and lying. Twenty-five sows in various stages of gestation were measured, and their behaviors were recorded continuously for 24 h. Negative correlations were found between both stall length and sow length with the duration of time the sows were standing. The time taken to change from standing to lying posture was negatively correlated with stall length relative to animal length. Similar correlations were noted between stall width relative to animal width and the duration of postural change from standing to sitting and from sitting to standing. Stall width relative to animal width was negatively related to the frequency of postural change from standing to sitting. Consequently, the ability of pregnant sows in stalls to get up and lie down could be improved by increasing the space allowance within the stall. Cariolet et al. (1997) also examined postures of gestating sows housed in stalls of different widths and observed more sows in full recumbency with the wider gestation stall.

Producers have used two types of tethers (neck and girth); both of which restrict sow movement. Tethering may cause a sow to attempt to escape, especially when sows first experience the tether (Hansen and Vestergaard, 1984; Becker et al., 1985). Schouten and Rushen (1992) found that trough-directed ONF behaviors (defined as those behaviors surrounding the time when the sow had her snout in the food trough) were increased in neck-tethered sows compared with group-housed sows. Sows were tethered for 2 mo, and as the duration of tethering increased, tethered sows rested less. McGlone et al. (1994) found that stalled gilts and sows were more active overall than girth-tethered gilts and sows.

Social Behaviors. Social behavior is clearly influenced by housing system. In theory, auditory, olfactory, visual, and limited tactile communication are possible across tether and stall partitions as well as some direct contact of the snout with neighboring animals. However, full body contact when resting is not possible when sows are housed in tether or stall systems, nor is it possible to determine dominance-submissive relationships between neighboring sows.

Blackshaw and McVeigh (1984) compared group-housed sows, stalled sows, and neck-tethered sows. Grouped sows showed more agonistic behavior (the combination of aggressive and submissive behaviors). Within-group agonistic behavior is exhibited especially at mixing and around feeding time (Arey and Edwards, 1998). Sows in tethers may show aggressive behavior toward neighbors (Barnett et al., 1987), but adding partial barriers can reduce aggressive behaviors among neighbors (Barnett et al., 1989).

Morris et al. (1993) compared the Hurnik-Morris (**HM**) system, which permits socially coordinated eating and resting, controlled and socially undisturbed feed intake (electronically fed in individual compartments outside of the pen), physical exercise, and regular exposure to boars, with individual gestation stall housing. Four pens containing six gilts per pen with a floor space that allowed 2 m^2 per gilt represented the HM system. These gilts spent less time lying in sternal recumbency (21% *vs* 31%) and performing sterotypies (0.1% *vs* 56%) and spent more time participating in social activities such as touching (1.4% *vs* 0.19%) than similar gilts kept in gestation stalls with a floor allowance of 1.6 m^2 per gilt. Behavioral differences between the HM and stall system may be the consequence of numerous factors: different space allowance, exercise levels, inadequate housing complexity, or lack of occupational opportunities in the stall housing system (e.g., absence of bedding, reduced social interaction, and restrictive surroundings).

Weng et al. (1998) measured how behavior and social interactions were affected by floor space (2, 2.4, 3.6, and 4. 8 m^2) with individual feeding stalls and related this to a physical indicator of welfare, the level of skin lesions. The behavior of six multiparous sows per pen, bedded on straw, was recorded. Time spent rooting increased progressively with increasing space allowance, whereas sitting and standing inactive were both progressively reduced. The total frequency of social interactions and aggressive behavior both decreased with increasing space allowance. The results indicated that a minimum space between 2.4 and 3.6 m^2 per sow was necessary to reduce social aggression for sows in straw-bedded pens.

Summary of Behavioral Measures. In general, outdoor sows show a more pronounced bi-phasic activity pattern (Tober, 1996; Dailey and McGlone, 1997b; Buckner et al., 1998). In studies where stereotypic ONF behaviors are distinguished from non-stereotypic ONF behaviors, tethered and stalled sows exhibited more post-feeding stereotypic ONF behaviors than group-housed sows.

However, overall ONF behaviors were comparable between different gestation sow housing systems. Compared with group housing, individually confining sows during gestation resulted in postural and movement restrictions. This restriction may depend on the size of the stall, which can influence sow maneuverability. However, individually housed sows can be protected from aggressive physical interactions if partitions are in place. Group-housed sows may show more agonistic behavior, but individually kept sows are not entirely protected from aggressive physical interactions. Stall division type may influence aggressive interactions with neighbors.

Gaps in Knowledge of Comparative Gestation Housing Systems and Behavior. A number of studies included extensive behavioral measures on individual sows, but, in some studies, the group pen was not replicated. This was especially a problem for ESF systems. To understand the behavioral effects of various group housing systems better, there is a need to replicate pens within farms while using common stockpeople. Furthermore, there is a need to replicate system comparisons across geographical locations. If multiple locations were evaluated, a meta-analysis would be possible to look for robust effects.

Behavioral details varied among studies. Complete ethograms were not always provided in published papers, nor are behavioral methods standardized among investigators. If behavioral methods were standardized, then across-study comparisons could be made with more certainty. There is a need for a complete ethogram in conventional and alternative systems.

Management of specific behaviors needs to be better described in papers and further studied. How might aggressive behavior be managed? What additional care might be needed? When alternative systems are designed, social behaviors and particularly aggressive and dominance-submissive interactions need to be an area of focus. Within-pen variation in some measures in a study that includes pen replication may add useful information on the effects of social behaviors on sow welfare.

Oral-nasal-facial behaviors are not well understood, and the scientific literature contains much confusion about ONF behaviors. The cause and function of ONF behaviors need to be determined in more basic studies. Categories of ONF behaviors, especially stereotyped and non-stereotyped ONF behaviors, can be determined once mechanisms of the cause and function of ONF behaviors are better understood (Lawrence and Rushen, 1993).

Further research is needed on gestating sow behavioral needs. Such studies should include measures of motivation so that alternative systems can be based on a better understanding of behavioral needs. Use of semi-natural environments as a control treatment group may aid our understanding of sows' behavioral needs.

Gestation Housing Effects on Performance and Health. When reviewing the scientific literature, few studies provided a complete matrix of comparisons of each housing system for each outcome of concern in health and performance. Nonetheless, there is a large body of information on housing systems that allows us to understand the relative benefits and constraints of each system better. Descriptive field data from many farms implementing various housing systems has some value in this effort. Production measures or outcomes can provide useful insights into housing system efficacy. The outcomes that the authors considered sensitive to the effects of stress include risk of injury, longevity, weaning-to-estrus interval, farrowing rate, litter size, piglet birth weight, and nutrient intake.

Risk of Injury. Vulva biting is a major problem with some group-housing systems (Edwards and Riley, 1986; van Putten and van de Burgwal, 1990; Rizvi et al., 1998). Olsson et al. (1992) concluded in a literature review that injuries, wounds, and vulva lesions occur more frequently in herds with ESF than in other group-housing configurations. Two studies (Gjein and Larssen, 1995; Rizvi et al., 1998) reported a greater risk for vulva injuries in group housing over tethers or stalls. Gjein and Larssen (1995) reported that no vulva lesions were apparent on sows housed with either tethers or stalls; however, the prevalence in group housing was 15.2%. All lesions were associated with biting. The relative risk of vulva lesions was 2.6 times greater in group housing with no roughage compared with group housing with roughage feeding. System design and mechanical failure may be contributing factors to injuries within the ESF system design (Edwards and Riley, 1986).

In a study by Gjein and Larssen (1995), the prevalence of body lesions was 13.1% in group-housed sows; 4.0% of individually housed sows had body lesions. Decubital ulcers on the shoulders were the main lesion in individually housed sows, and aggression was the major cause of body lesions in group-housed sows. Sows in group housing that were not fed additional roughage had an increased risk (1.7 times) of body lesions than sows in herds where additional roughage was fed. In this study, reasons for culling and production results were similar in the group- and stall-housed herds.

Boyle et al. (2002) reported no difference in total and hind limb lesions between gestation stall-housed and loose-housed sows when moved to farrowing stalls. However, with increasing time in the farrowing stall, forelimb lesions became significantly more severe among sows that had previously gestated in stalls compared with loose housing.

Claw lesions were reported to be more common in loose-housed sows than in either tethered or stall-housed sows (Gjein and Larssen, 1995). Mean herd prevalence for claw lesions in loose-housed herds with partially slatted floors was about twice as great as herds with individually housed sows. In this study, one herd housed in groups with deep straw bedding had a lesser prevalence of major claw lesions when compared with other loose, tethered, or stall-housing configurations. Backus et al. (1997) found sows kept in the ESF or trickle-feeding system without bedding experienced significantly more locomotor disorders (19.5 and 17.8%, respectively) than did sows kept in stalls or free-access stalls (8.4 and 10.4%, respectively). Mortensen (1990) found a greater frequency of mammary gland disease in group-housed gilts at farrowing than in tethered gilts; however, no differences among housing systems were found in older sows.

Longevity. Information on sow longevity in relation to sow housing systems is lacking. Den Hartog et al. (1993) demonstrated a significant difference between the replacement rate of sows in stalls (43.0%) *vs* those tethered (53.2%) or group-housed (55.6%). Svendsen et al. (1975) reported that a proportionally lesser percentage of the sows were culled in herds where the dry and pregnant sows were kept in stalls and/or tethered compared with herds where sows were housed in pens. It is unclear if culling may be due to housing system direct or indirect effects or to non-related reasons.

Weaning-to-Estrus Interval. Few studies examined the relationship between housing system and weaning-to-estrus interval. The weaning-to-estrus interval was 0.7 to 1.1 d shorter in sows housed in closed or free-access stalls compared with those kept in gestation groups, according to a study by Backus et al. (1997). Compared with individually kept pregnant sows, group housing did not affect estrus detection rate or duration of estrus, but did affect time to onset or interval from onset to ovulation (Langendijk et al., 2000).

Farrowing Rate. Many investigators compared farrowing rates between sows kept in groups and those in individual stalls during gestation (England and Spurr, 1969; Schmidt et al., 1985; Bokma et al., 1990; Den Hartog, 1993). In a retrospective study, Peltoniemi et al. (1999) reported a greater re-breeding rate (lesser farrowing rate) in sows that were group-housed compared with sows housed in individual stalls with no effect of housing system on litter size. McGlone et al. (1994) reported decreased farrowing rates in neck-tethered sows compared with sows in groups or individual stalls.

Sows housed outdoors may be exposed to greater environmental extremes such as temperature, sunburn, and parasites; however, the effects of these elements are not well documented in the literature. A recent study indicated reproductive performance of sows in stalls and intensive outdoor systems were not different (Johnson et al., 2001).

Love et al. (1995) demonstrated a significant improvement in farrowing rate in stall-housed sows over loose-housed sows during the hot season of the year. During the hot season, farrowing rate may be negatively affected in early pregnancy by a decrease in the concentrations of luteinizing hormone and because the sows are placed on restricted feed (Peltoniemi et al., 2000).

Litter Size. Backus et al. (1997) reported no differences in number of live-born piglets among sows housed in stalls, free-access stalls, ESF group systems, or trickle-feeding group systems. Den Hartog et al. (1993), however, reported lesser numbers of piglets born alive to sows tethered during pregnancy compared with sows kept in stalls or group pens (10.32 ± 3.0 *vs* 10.07 ± 3.0 pigs born alive per litter for sows in stalls and tethers, respectively; n = 1889 litters). Boyle et al. (2002) suggested that housing treatment has no effect on duration of farrowing, which is a significant contributor to stillbirth rate.

Birth weight. Den Hartog et al. (1993) and Backus et al. (1997) reported a significant reduction in average birth weights of piglets born to sows housed in an ESF group-housed configuration compared with sows kept in individual stalls, free-access stalls, or trickle-feeding systems. Piglets from girth-tethered sows had significantly heavier BW (but reduced litter size) compared with piglets from stall-housed sows (McGlone et al., 1994).

Nutrient Intake. Variation in feed or water intake may contribute to variations in sow BW or body condition. Backus et al. (1991) reported water use disappearance per sow per year was 14.8 L/d in tethered sows and stall-kept sows compared with 7.7 L/d for grouped sows. However, there was considerable individual animal variation in water use.

Summary of Performance and Health Measures. Sows kept in stalls had greater or equal reproductive performance as sows in group housing systems. Sows in some ESF group housing systems had injury scores in some body regions greater than sows kept in stall or tether systems. The tether system was associated with decreased reproductive efficiency in some studies.

Gaps in Knowledge of Comparative Gestation Housing Systems & Performance and Health. For proper implementation of group-housing systems, there needs to be additional research on group feeding systems that could minimize the prevalence of injuries to the gestating gilt or sow. Such research needs to include the design and management of trickle feeding, newer ESF and floor feeding systems, and the optimal number of sows per social group. Feeding systems may interact with pen type to influence the rate of gilt and sow aggressive behaviors and injury rates.

Housing systems represent a collection of individual system components; many of which may, singly or in combination with other system components, impact gilt or sow welfare. The following system components should be taken into account when designing future sow housing comparative studies: water use and the prevalence of urinary tract infections (Madec et al., 1986), group size (Weng et al., 1998), genetics, roughage availability (Spoolder et al., 1997), the effect of moving and mixing sows during early pregnancy (Schmidt et al., 1985; Bokma, 1990), removal from the group 1 wk prior to farrowing, use of bedding, feeding frequencies, and housing a boar in the sow pen (Rizvi et al., 1998).

Comparisons of gestation housing system effects on longevity, injury, and lameness in the breeding herd require further clarification. Particular emphasis should focus on the interaction of flooring type with housing design and the overall system components that could influence bone strength (Marchant and Broom, 1996) using replicated, comparative studies.

Over the past 10 yr (1992 to 2002), the US pig industry has consolidated, and genotypes and facilities have changed significantly. During this period, few studies were found that compared whole systems for gestating sows. The authors of this review favored a multidisciplinary approach in the evaluation of sow housing systems. When entire production systems are compared, conclusions should be drawn on a systems level. Furthermore, conclusions would be strengthened by having well-controlled studies at multiple locations. Relatively few scientific studies were available that directly compared the behavior, physiology, and performance of sows housed in different gestation systems. More sound, multi-disciplinary, long-term research is needed on the subject of gestation sow housing systems.

Implications

Within the restrictions of the methodology adopted in this review, the authors found no clear scientific evidence from comparative studies indicating that stalls or well-managed pens caused consistent and significant signs of stress among pregnant gilts or sows in terms of physiology, behavior, or productivity. Each system for housing gestating sows has opportunities for improvements in sow welfare based on additional research and development.

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