



Review: updated scientific evidence on the welfare of gestating sows kept in different housing systems

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Review

Running Heading: *Updated Review of Gestation Sow Housing Literature*

Review: updated scientific evidence on the welfare of gestating sows kept in different housing systems

John J McGlone¹, PAS, ACAWS

Laboratory of Animal Behavior, Physiology and Welfare², Department of Animal and Food Sciences, Texas Tech University, Lubbock, TX 79409-2141

Correspondence:

John J. McGlone, PhD
Professor and Institutional Official
Animal and Food Sciences Department
Texas Tech University
Lubbock, TX 79409-2141
phone: 806-742-2805, ext. 246
fax: 806-742-4003
john.mcglone@ttu.edu

¹ Correspondence: john.mcglone@ttu.edu.

² <http://www.depts.ttu.edu/animalwelfare/>

ABSTRACT

1
2 Gestation sow housing is a contemporary animal welfare issue with legislative actions in the
3 USA states to ban individual gestation sow systems. This review sought to summarize the
4 scientific literature since earlier reviews were published in 2004 and 2005. Seventeen papers
5 comparing effect of housing systems on the welfare of gestating sows were published from
6 2005 to 2012. Stalls/crates, tether housing, and group pens including conventional group
7 pens, loose-house pens, electronic sow feeders (ESF) pens, and hoop barns were reported.
8 The majority of recent findings were similar to the previous conclusions from papers and
9 reviews. Cortisol concentrations were not different between stalled and group penned sows
10 but were higher shortly after mixing in concert with increased sow aggression and skin
11 lesions. The effects of gestation housing system on neutrophil:lymphocyte ratio was still
12 mixed. In the recent literature, stereotypies were greater among stalled sows compared with
13 group penned sows which may reflect a change in sow genetics since the basic housing
14 systems have not changed. Recent papers indicated more sitting/standing inactive, leg and
15 claw problems, and farrowing rate among stalled sows, higher lying among group penned
16 sows, and no differences in other reproductive and productivity measures between stalled and
17 group penned sows. Weaning-to-estrus intervals were similar between stalled and group
18 penned sows in contrast to previous reviews that observed a shorter interval among stalled
19 compared with grouped sows. In conclusion, recent papers found similar productivity,
20 physiology health and behavior among individually or grouped sows during gestation.

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22 Key words: Pig, Sow, Gestation housing, Welfare
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26 INTRODUCTION

27 Gestation sow housing is a social issue in Europe, North America, Australia and New
28 Zealand. The primary concern is about the welfare of pregnant sows kept in individual
29 gestation crates (also called stalls). The gestation crate does not allow the sow to turn around
30 or make normal postural adjustments. However, the gestation crate is the most common
31 system used in the USA because it minimizes space needs and provides a mean to
32 individually feed and care for pregnant sows. Tether housing and crates or stalls for
33 individual sows have been perceived as housing systems that cause poor welfare. Therefore,
34 European countries and several states in USA (FL, CA, AZ, OR, CO, RI, at least) have
35 banned or are phasing out gestation crates. Retailers (grocery and restaurant) have made
36 public statements that they will preferentially buy pork from farms that do not use gestation
37 crates. Still, the industry defends the gestation crate as a viable sow housing system.

38 Two reviews of the scientific literature about the welfare of pregnant sows were
39 published in 2004 and 2005 (McGlone et al., 2004; Rhodes et al., 2005). In the past 8 years
40 more research has been published that sought to compare the welfare of pregnant sows in
41 individual gestation crates and group pens. The objectives of this review were (a) to
42 summarize the current scientific literature on the welfare of gestation sow housing systems
43 and (b) to determine if the conclusions of the recent literature differ from the conclusions of
44 the previous reviews. Finally, we speculate on the current status of the welfare of pregnant
45 sows in housing systems based on the newer scientific literature.

46

47 SYSTEMS REVIEWED

48 The “control” system by which other systems are compared is the gestation stall (also
49 called crate). This is the control or standard system because at this time, in North America, it
50 is the most common system to keep pregnant sows. Any change away from the crate will

51 incur an economic cost to pork producers and ultimately the consumer. We should know if
52 this seemingly inevitable economic cost is associated with better, the worse or the same sow
53 welfare. While we find a plethora of systems in which to keep pregnant sows, only a few
54 have generated sufficient scientific literature in which comparisons can be made. These
55 group-housing systems include the (a) group penning with or without individual feeding
56 stalls, and (b) ESF. Other systems included in the earlier reviews from which we found
57 insufficient new literature were the outdoor system, neck or girth tethers, turn-around stalls,
58 and the Hurnik-Morris system. Because only one paper investigated girth tethers and
59 only two papers examined loose-housing in hoop barns, these system will be mentioned but
60 not highlighted.

61 The scope of this updated literature review is to compare individual with group
62 keeping systems for pregnant sows. Papers have been published with single systems or in
63 ways that ask specific questions about sow preferences or other questions about sow
64 behavior, physiology or health. These papers were not considered here because they did not
65 compare sow keeping systems.

66 Group housing systems are more accepted by some people because as they allow the
67 animals to express social behaviors and sows can turn around. However, group pens also pose
68 welfare problems due to fighting of sows to compete for limited resources and in the
69 establishment of a social hierarchy (Spoolder et al., 2009). Adopting a housing system that is
70 good for the overall welfare of the sows should rely on scientific research results that cover
71 several relevant welfare indicators such as behavior, physiology, health, reproduction, and
72 productivity (CAST, 2009).

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MEASURES OF SOW WELFARE

75 Multiple measures of sow welfare should be used in any evaluation of
76 housing/penning systems. For this review, as with past reviews, we considered three types of
77 measures to be direct or indirect measures of sow welfare. These categories include (a)
78 physiology, (b) behavior, and (c) health, reproductive performance and productivity. The
79 categories could be split or merged, however, given that relatively few papers collected all
80 measures.

81 Measures of physiology focused on the stress hormone cortisol (which may rise
82 during stress) and immune measures (which may increase or decrease during stress; Salak-
83 Johnson and McGlone, 2007). Other measures of physiology like heart and respiratory rates
84 were not often measured in the more recent literature.

85 Measures of behavior include maintenance behaviors (sitting, standing, lying, feeding,
86 drinking) and various forms of oral-nasal-facial (ONF) behaviors, including stereotyped
87 behaviors. One particular type of ONF behavior called “stereotypies” is thought by some to
88 be critical measures of sow welfare and thus was summarized. Because of the difficulty of
89 defining which ONF behaviors are and are not “stereotypies, we largely considered all ONF
90 behaviors. However, we acknowledge other views related to the interpretation of ONF
91 behaviors (Damm et al., 2005).

92 The category of measures including health, reproduction and productivity is very
93 broad. Health measures that were tied to a putative stress response were included in
94 measures of physiology. Measures of reproductive health and productivity are connected and
95 logically can be in one category. Health also includes bone and foot and leg health and body
96 and vulva lesions.

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METHODS

99 The scientific literature was searched electronically. Agricola, Pubmed, and Google
100 Scholar were searched from the period of Jan 1, 2005 through August 1, 2012. Keywords
101 included sow and/or pig, housing or penning. In addition, journals known to contain papers
102 on pig biology were searched including The Journal of Animal Science, The Professional
103 Animal Scientist, Livestock Science, Applied Animal Behaviour Science, Animal, Animal
104 Welfare, Journal of Applied Animal Welfare Science and Journal of Swine Health and
105 Production.

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FINDINGS

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Physiology

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Results from 17 publications from 2005 to 2012 comparing housing systems for gestating sows in a variety of aspects relating to welfare were summarized in each animal welfare category. Methodologies used in the reviewed studies are presented in Table 1. Details of the findings by measure are provided in Tables 2 to 6.

Blood or salivary cortisol concentrations have been used to determine stress among gestating sows in housing systems. Comparing stall- and group-kept sows, most authors found no differences in cortisol concentrations. The recent literature confirms the earlier reviews that sows in stalls or group pens may equally adapt to the environments by mid gestation. Group-kept sows are often mixed and this results in fighting and an elevation in cortisol (Jansen et al., 2007). Associations among mixing of grouped sows, aggressive interactions, and cortisol have been investigated in studies dealing with grouping of sows in a single system but not including a comparison of sows in crates and group pens. Therefore, these papers were not included in this review. After the social hierarchy was established, no differences were observed in cortisol concentrations between crated and group penned sows

124 (Hulbert and McGlone, 2006; Karlen et al., 2007). Cortisol was also elevated when group-
125 penned gestating sows were moved to farrowing crates compared with sows crated during
126 gestation and moved to farrowing crates (Sorrells et al., 2007).

127 For stress-related immune measures, there were inconsistent results. Karlen et al.
128 (2007) found higher neutrophil:lymphocyte ratios measured at 15 weeks of gestation among
129 stalled sows compared with group penned sows. In contrast, Hulbert and McGlone (2006) did
130 not find differences in neutrophil:lymphocyte ratios, % neutrophil phagocytosis, and
131 neutrophil chemotaxis measured at mid gestation between individually crated and group
132 housed sows.

133

134 **Behavior**

135 Some authors argue ONF behavior should include feeding and drinking behaviors
136 (McGlone et al., 2004) while others argue ONF should not include feeding and drinking oral
137 behaviors (Damm et al.(2005). Setting this argument aside, one class of ONF behaviors --
138 the stereotypies directed to objects such as bars and feeders -- were greater among stalled
139 sows compared with group penned sows (Karlen et al., 2007). These recent findings are
140 consistent with the results from the previous reviews.

141 Sitting or standing inactive for long periods may indicate poor welfare according to
142 both the previous reviews and the current literature. Lying, in the opposite way, may reflect
143 good welfare as shown if the lying behaviors in group penned sows increased. Hulbert and
144 McGlone (2006) found no difference in behavior for sows kept in stalls or group pens.

145 Findings about aggressive behaviors were consistent in the recent literature that
146 evaluated group housing. Sows show an increase in aggressive interactions after weaning or
147 mixing after breeding (Jansen et al., 2007). Seguin et al. (2006) and Salak-Johnson et al.

148 (2007) investigated the effects of space allowance on lesion scores but not on aggressive
149 behavior; nor did they have a direct comparison with individually-kept sows.

150

151 **Health, Reproductive Performance & Productivity**

152 Body lesions (mostly resulting from fighting especially shortly after mixing) and
153 locomotory problems have been investigated to determine welfare of sows housed in different
154 systems. Concerning foot and leg problems, results were mixed. Conventional group penned
155 sows and those kept in ESF had more lameness scores and claw lesions than stalled sows
156 providing there was no bedding (Harris et al., 2006; Anil et al., 2007). In contrast, Karlen et
157 al. (2007) reported more lameness among stalled sows than group penned sows provided
158 deep bedding. However, in an epidemiological study, Ryan et al.(2010), observed similar
159 lameness scores and joint pathologies between sows housed in stalls and loose-housed pens
160 where bedding was provided. Therefore, lameness may be more a function of the absence of
161 bedding rather than housing system.

162 The previous reviews concluded that weaning-to-estrus interval in gestating sows
163 reared in stalls was shorter than those kept in group pens. However, from the current results,
164 weaning-to-estrus interval and also weaning-to-service interval were not different between
165 stalled and group penned sows. Farrowing rates were lower in group penned sows compared
166 to stalled sows. However, Hulbert and McGlone (2006) did not find a difference in
167 reproduction between crated and grouped sows. Other reproductive parameters also indicate
168 no difference due to housing. On the whole, reproductive performance was similar for sows
169 in group pens and individual crates in the current literature.

170 Several reports showed no difference in litter size for sows housed in stalls compared
171 with any type of group pens (Harris et al., 2006; Hulbert and McGlone, 2006; Jansen et al,
172 2007; Karlen et al., 2007; Salak-Johnson et al., 2007; Chapinal et al., 2010a). However, one

173 study found greater litter size among group penned sows compared with individually crated
174 sows (Seguin et al., 2006).

175 Sorrells et al.(2006) studied prenatal stress in piglets born from gilts housed in stalls
176 or pens. These findings may not be directly relevant to the welfare of gestating sows but may
177 relate to the welfare in the entire system since the welfare of piglets may be impacted by
178 gestation housing system.

179

180 **CONCLUSIONS**

181 Cortisol concentrations may be used as a physiological sign of stress. Cortisol
182 concentrations were higher among group penned sows shortly after mixing (Jansen et al.,
183 2007). However, cortisol concentrations were not different between stalled and group-
184 penned sows in mid gestation. Differences in immune measures were not detected between
185 crated and penned sows. Physiological measures, on the whole, were not different between
186 individually crated and group-kept pregnant gilts and sows. This is consistent with the earlier
187 reviews.

188 Overall ONF behaviors did not differ among sows in group or individual systems. In
189 contrast, stereotypies were higher among stalled sows than group penned sows in one paper
190 (Karlen et al., 2007) but not another (Hulbert and McGlone, 2006). Excessive sitting and
191 standing inactive may indicate poor welfare. More sitting and/or standing inactive were
192 reported in stalled sows compared to groped sows (Munsterhjelm et al., 2008; Weng et al.,
193 2009), however, Hulbert and McGlone (2006) did not find this.

194 Aggression commonly occurs in group penned sows particularly shortly after mixing
195 and during feeding. This aggression leads to body or vulva lesions (Jansen et al., 2007; Salak-
196 Johnson et al., 2007;Chapinal et al., 2010a;Chapinal et al., 2010b).

197 Because the housing systems have not changed, it is possible that the selection for
198 improved reproductive performance or other traits has resulted in sows that express more
199 stereotypies when individually crated. One cannot draw this conclusion on the basis of just a
200 few recent papers. However, it is an interesting hypothesis that recent intensive genetic
201 selection may have changed the behavior of pregnant sows perhaps with increased
202 aggressive, sitting and ONF behaviors.

203 Both recent studies and the earlier reviews found that leg and foot problems had a
204 greater incidence in group penned sows than crated sows (McGlone et al., 2004; Harris et al.,
205 2006; Anil et al., 2007). However, lameness issues may be more a function of bedding (or
206 lack of bedding) than penning system (Karlen et al., 2007).

207 In the recent literature, no differences were observed in weaning-to-estrus interval
208 among stalled versus group-kept sows. Higher farrowing rates were reported among stalled
209 sows compared to group penned sows. Other reproductive parameters such as ovulation rate,
210 number of embryo, embryo survival, backfat thickness, and body condition scores were
211 similar among sows kept in stalls or group pens. Most studies indicated no difference in litter
212 size and birth weight of piglets born from sows housed in stalls or group pens. The majority
213 of the current findings from 2005 to 2012 were not different from those in the previous
214 review. On the whole, few physiological, behavioral or health differences were reported
215 between individually crated and group-kept pregnant gilts and sows.

216

217 **Implications**

218 Overall, group penning and individual crating of pregnant sows support about the
219 same level of measurable sow welfare. Grouping has negative consequences such as more
220 body lesions, and aggression when grouped. Individual crating may cause more stereotyped
221 behaviors of unknown cause or consequence, although this observation was not consistent

222 across studies. A compilation of the recent scientific literature does not draw one to a
223 different conclusion than the literature summarized in 2004 and 2005. Improvements in the
224 welfare of sows are possible in each pregnant sow keeping system.

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For Peer Review

Table 1. Methodologies in reviewed recent literature.

Authors	Animals, parities	Housing systems compared	Space allowance (m ² /sow)	Bedding	Group sizes, replicates	Measures
Chapinal et al. (2010a)	Landrace x Large White; parities 1-9	Stall (S) group pen (P) unprotected ESF group pen (ESF)	1.29 (S) 2.76 (P) 2.32 (ESF)	No	20 stalled sows, 2 group pens of 10 sows, and an ESF pen of 20 sows x 3 replicates	<ul style="list-style-type: none"> • Behavior (week 1-2 and then every week) • Haptoglobin and Pig-MAP (week 11-13 and 16-18) • Reproduction • Productivity • Lameness and injury
Chapinal et al. (2010b)	Landrace x Large White; parities 1-9	Group pen (P) ESF group pen (ESF)	2.76 (P) 2.32 (ESF)	No	2 group pens of 10 sows and an ESF pen of 20 sows x 3 replicates	<ul style="list-style-type: none"> • Aggressive behavior
Ryan et al. (2010)	Cull sows in 8-9 parities (studied at the abattoir)	Stall, loose-house	NA	Yes (straw for loose-house)	4,120 stalled sows from 5 farms, 2,900 loose-housed sows from 2 farms (group size of 100)	<ul style="list-style-type: none"> • Lameness score • Joint pathologies
van der Staay et al.(2010)	Great Yorkshire/Large White x Dutch Landrace; parities 2-13	Tethering (T), loose house (L)	2.2 (L)	No	59 loose-housed sows (65-130 sows/pen), 70 tethered sows	<ul style="list-style-type: none"> • Plasma cortisol • Weights of adrenal, pituitary, and spleen • mRNA of PrP and β-globulin in brain
Weng et al.(2009)	Landrace x Yorkshire gilts	Stall S) group pen (P) ESF group pen (ESF)	1.41(S) 1.80 (P) NA (ESF)	No	16 stalled sows, 16 group penned sows (5 sows/pen), 32 ESF sows	<ul style="list-style-type: none"> • Behavior at 8 physiological stages from estrus to dry

Munsterhjelm et al.(2008)	Yorkshire (64%), Yorkshire x Finnish Landrace (36%), averaged parities 2.4	Stall, group pen	1.44 (S) 5.10 (P)	Yes (deep litter for pen)	240 stalled sows, 240 group penned sows (12 pens of 20 sows)	<ul style="list-style-type: none"> • Behavior (day 27 after weaning) • Reproduction • Productivity
van Wettere et al.(2008)	Purebred maternal (Large White)/terminal (Duroc)	Stall, group pen	1.36 (S) 2.40 (P)	No	24 stalled sows, 4 group pens of 6 sows x 3 mixing treatments	<ul style="list-style-type: none"> • Reproduction
Anil et al.(2007)	Gilts and sows; parities 0-8	Stall, ESF group pen,	1.20 (S) NA (ESF)	No	82 stalled sows, 102 group penned sows (no group size mentioned)	<ul style="list-style-type: none"> • Claw lesions measured at day 110 of gestation
Jansen et al.(2007)	Landrace and Yorkshire; parities 0, 1, 3	Stall, group pen	NA (S) 2.10 (P)	No	48 stalled sows, 48 group penned sows (mixed with other sows in 4 pens to form a group of 50)	<ul style="list-style-type: none"> • Behavior (0-3 d after mixing) • Lesion scores (+1, -1 d of mixing) • Salivary cortisol (+1, -1 d of mixing) • Reproduction
Karlen et al.(2007)	Landrace x Large White; parities ≥ 1	Stall, group pen	1.26 (S) 2.30 (P)	Yes (deep rice hull for group pen)	640 sows in total, group size of 85	<ul style="list-style-type: none"> • Behavior (week 1, 9 of gestation) • Salivary cortisol (day 5, week 9 of gestation) • Hematology and lymphocyte proliferation (week 15 of gestation) • Reproduction
Lammers et al.(2007)	25% Hamshire x 50% Yorkshire x 25% Landrace;	Stall (S), hoop barns (H)	1.26 (S) 3.44 (H)	Yes (deep cornstalks for hoop)	552 stalled sows, 405 group penned in hoop barns (32	<ul style="list-style-type: none"> • Productivity

	parities 0-2			barns)	sows/pen, 2 pens/barn, 2 barns)	
Salak-Johnson et al.(2007)	Sows (PIC) in parities ≥ 1	Stall, group pen	1.29 (S) 1.40, 2.30, and 3.30 (P)	No	51 stalled sows, 166 group penned sows (group size of 5)	<ul style="list-style-type: none"> • Productivity • Lesion scores (every 3 d for the first 2 weeks, then every week of gestation)
Sorrells et al.(2007)	Landrace x Yorkshire gilts	Stall, group pen	1.32 (S) 2.34 (P)	No	16 stalled gilts, 8 group pens of 4 gilts	<ul style="list-style-type: none"> • Cortisol , cytokines, and acute phase proteins during gestation and after farrowing
Harris et al.(2006)	Landrace x Yorkshire gilts	Stall, group pen	1.35 (S) 2.40 (P)	No	16 stalled gilts, 8 group pens of 4 gilts	<ul style="list-style-type: none"> • Behavior (week 4, 6, 9, and 13 of gestation) • Lesion scores (every 2 weeks) • Productivity
Hulbert and McGlone (2006)	Camborough 22 gilts	Stall, group pen	1.33 (S) 1.28 (S)	No	80 stalled gilts, 80 group penned gilts	<ul style="list-style-type: none"> • Behavior (50-60 d of gestation) • Cortisol (50-60 d of gestation) • Hematology and immune (50-60 d of gestation) • Reproduction • Productivity
Seguin et al.(2006)	Yorkshire; parities 2.8	Stall, group pen	2.00 (S) 2.30, 2.80, and 3.20 (P)	No	98 stalled sows, 9 small group penned sows (group size of 11-19), 6 large group penned sows (group size of 22-31)	<ul style="list-style-type: none"> • Lesion scores (+1,-1 d of mixing, then every week for 5 weeks) • Productivity
Sorrells et al.(2006)	Landrace x Yorkshire gilts	Stall, group pen	1.35 (S) 2.41 (P)	No	16 stalled gilts, 8 group pens of 4 gilts	<ul style="list-style-type: none"> • Behavior (isolation test in piglets)

						<ul style="list-style-type: none">• Cortisol, acute phase proteins, IgG, and TNF-α in piglets
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For Peer Review

Table 2. Effects of housing on physiology of gestating sows

Findings from the previous reviews in 2004 (McGlone et al., 2004) and Rhodes et al.(2005)	Findings from 2005-2012
<p>Cortisol</p> <ul style="list-style-type: none"> • Circulating cortisol concentrations of stalled and group penned sows did not differ. However, the concentrations in tethered sows were greater compared to those in stalled or group penned sows. <p>Immune responses</p> <ul style="list-style-type: none"> • Housing did not influence neutrophil: lymphocyte ratio, immunoglobulin concentrations, antibody response against sheep red blood cell antigens, and natural killer cell activity. <p>Cardiovascular functions</p> <ul style="list-style-type: none"> • There was no information comparing cardiovascular response of sows in different housing systems. 	<ul style="list-style-type: none"> • Tethered sows had higher plasma cortisol than loose-housed sows (van der Staay et al., 2010). No variation in concentrations of plasma cortisol measured during 50-60 days of gestation between sows housed in crates and group pens (Hulbert and McGlone, 2006). • Salivary cortisol concentrations measured at 1 and 9 weeks of gestation were not different between stalled and group penned sows (Karlen et al., 2007). However, Jansen et al. (2007) found significantly higher salivary cortisol concentrations in group penned sows the day of relocation compared to prior moving. In addition, group penned gilts had higher salivary cortisol levels shortly after moving to farrowing crates compared to stalled gilts (Sorrells et al., 2007). • There were no differences in neutrophil: lymphocyte ratio, % neutrophil phagocytosis, and neutrophil chemotaxis between crated and group penned sows (Hulbert and McGlone, 2006). • Stalled sows had higher neutrophil: lymphocyte ratio than group penned sows (Karlen et al., 2007). • No differences in cytokines m RNA expressions and acute phase proteins between stalled and group penned gilts (Sorrells et al., 2007) • Stalled and group penned sows had similar heart rates at rest and during activities (Harris et al., 2006).

Table 3. Effects of housing on behavior of gestating sows

Findings from the previous reviews in 2004 (McGlone et al., 2004) and Rhodes et al.(2005)	Findings from 2005-2012
<p>Oral-nasal-facial (ONF) behaviors and stereotypies</p> <ul style="list-style-type: none"> ONF behaviors in stalled and group penned sows were similar. Tethered sows might show higher or lower ONF behavior depending on experimental designs. Sows housed in group pens expressed less time spent for stereotypies than those housed in stalls. <p>Locomotory and postural behaviors</p> <ul style="list-style-type: none"> Gilts kept in turn-around stalls had more standing activity than stalled sows. An increase in space allowance reduced standing and sitting inactive of sows in group pens. Group pen sows changed more postures than stalled sows in farrowing stalls and more restless at parturition. 	<ul style="list-style-type: none"> Stalled and group penned sows had no difference in percentage of time spent for ONF behaviors (Hulbert and McGlone, 2006; Munsterhjelm et al., 2008). However, Chapinal et al.(2010a) reported that stalled sows spent higher proportion of time for ONF behaviors than group penned sows. Percentages of time spent for stereotyped interactions with bars and feeders were greater in stalled sows than group penned sows which was contrast to the percentage of time spent for stereotyped interactions with floor (Karlen et al., 2006). Munsterhjelm et al.(2008) found that stalled sows engaged more in standing inactive which was an indicator of poor welfare than group penned sows. More standing, sitting, rooting, and drinking were also observed in stalled sows than group penned sows and sows housed in Electronic Sow Feeding (ESF) system (Weng et al., 2009). ESF sows had higher time spent for lying and less time spent for rooting and drinking (Weng et al., 2009). This was consistent with the results of Chapinal et al. (2010a) indicating more lying in ESF sows than stalled sows and group penned sows with trickle feeding system. Karlen et al. (2007) reported more lying and less standing/walking at week 9 of gestation among stalled sows than group penned sows. However, Hulbert and McGlone (2006) did not find any difference in time budgets for lying, sitting, and standing/walking in crated and group penned sows.

<p>Social behaviors</p> <ul style="list-style-type: none"> • Agonistic behavior was higher in group penned sows particularly during mixing and feeding compared to stalled and tethered sows. Increased space allowance resulted in a decreased agonistic behavior and social interactions among group penned sows. 	<ul style="list-style-type: none"> • Total number of active and passive aggressive encounters was greater in group penned sows than stalled sows and during feeding than during after mixing (Jansen et al., 2007). When 2 types of group pens were compared, ESF penned sows had higher frequency of aggressive behavior than conventional group penned sows (Chapinal et al., 2010b). Karlen et al.(2007) also noted the decrease of fighting in group penned sows at 9 weeks of gestation compared to that in the first week. Results revealed by Hulbert and McGlone (2006) indicate no difference in agonistic behavior of crated sows and group penned sows at 50-60 days of gestation.
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Table 4. Effects of housing on health of gestating sows

Findings from the previous reviews in 2004 (McGlone et al., 2004) and Rhodes et al.(2005)	Findings from 2005-2012
<p>Vulva biting</p> <ul style="list-style-type: none"> Vulva injuries related to biting were more frequent in ESF sows than other types of group housing systems. There was no prevalence of vulva biting in stalled sows and tethered sows. <p>Body lesion scores</p> <ul style="list-style-type: none"> Group penned sows had 3 times in percentage of body lesions caused by fighting compared to stalled sows. Provision of roughage reduced a risk of developing body lesions in group penned sows. <p>Locomotory problems</p> <ul style="list-style-type: none"> Incidence of claw lesions was double higher in loose-housed sows than stalled sows and was also more common than tethered sows. Sows housed in group pens with deep bedding were found to have higher claw lesions than stalled and tethered sows. Without bedding, lameness incidence was greater in ESF and group penned sows compared to 	<ul style="list-style-type: none"> Higher numbers of sows developed vulva biting in ESF and group penned sows compared to stalled sows (Chapinal et al., 2010). However, Harris et al. (2006) did not detect difference in vulva lesion scores between stalled and group penned sows. Group penned sows had higher lesion scores than stalled sows after mixing and these scores correlated with the total number of agonistic interactions (Jansen et al., 2007). Salak-Johnson et al.(2007) noticed a decrease in space allowance (1.4 vs. 2.3 and 3.3 m²) leading to higher lesion scores in group penned sows. However, a study by Seguin et al.(2006) indicated that there was no difference in lesion scores of sows provided space allowance of 2.3, 2.8, and 3.2 m². The study by Hulbert and McGlone (2006) showed no dissimilarity in lesion scores measured at mid-gestation between crated sows and group penned sows. Group penned gilts lacking bedding had more foot and leg problems investigated at 13 weeks of gestation than stalled gilts (Harris et al., 2006). Karlen et al.(2007) reported higher lameness scores measured at 9 and 13 weeks of gestation among stalled sows than group penned sows provided deep bedding. Comparing ESF with stall housing, Anil et al.(2007) discovered higher proportion of sows kept in ESF developing claw lesions. However, based on the study of Ryan et al.(2010), lameness scores and joint pathology of culled sows previously

stalled and free –access stalled sows.	housed in stalls or loose-housed pens were not different
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For Peer Review

Table 5. Effects of housing on reproductive performance of gestating sows

Findings from the previous reviews in 2004 (McGlone et al., 2004) and Rhodes et al.(2005)	Findings from 2005-2012
<p>Weaning-to-estrus interval</p> <ul style="list-style-type: none"> Sows housed in stalls had shorter weaning-to-estrus interval than those housed in group pens. Group penned sows had similar estrus detection rate and estrus duration but longer time to onset and onset to ovulation than stalled sows. <p>Farrowing rate</p> <ul style="list-style-type: none"> farrowing rate in stalled sows was higher than group penned sows. Tethered sows had lower farrowing rate than stalled and group penned sows. There was no difference in farrowing rates of outdoor reared sows compared to indoor stalled sows. Stalled sows had greater farrowing rate than loose-housed sows during summer. 	<ul style="list-style-type: none"> Munsterhjelm et al.(2008) observed no difference in weaning-to-estrus between stalled and group penned sows. This was consistent with a report by Jansen et al.(2007). Also, weaning-to-service did not differ between stalled and group penned sows (Harris et al., 2006; Munsterhjelm et al., 2008). However, Lammers et al.(2007) noticed shorter weaning-to-service interval among stalled sows than group penned sows. Stalled sows had higher farrowing rate than group penned sows (Karlen et al., 2007). In contrary, Hulbert and McGlone (2006) found no variation in farrowing rates of sows housed in stall and group pens. van Wettere et al.(2008) also detected a similar in ovulation rate, number of embryos, and embryo survival in gilts kept in stalls and group pens. Body condition scores (BCS) evaluated before and after entering gestation did not differ in stalled and group penned sows (Seguin et al., 2006). Body weight and backfat thickness were also not different between stalled and group penned sows (Harris et al., 2006; Hulbert and McGlone, 2006; Chapinal et al., 2010a). Space allowance positively affected body weight, BCS, and backfat thickness (Salak-Johnson et al., 2007). There was a similarity in body weight at farrowing and weaning and backfat thickness at

	breeding, farrowing, and weaning in sows housed in crates or group pens (Hulbert and McGlone, 2006).
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For Peer Review

Table 6. Effects of housing during gestation on productivity of sows and behavior and physiology of offspring

Findings from the previous reviews in 2004 (McGlone et al., 2004) and Rhodes et al.(2005)	Findings from 2005-2012
<p>Litter size</p> <ul style="list-style-type: none"> Sows housed in stalls, free-access stalls, ESF pen, and group pens with trickle feeding had a similarity in litter size. However, tethered sows had smaller litter size than stalled and group penned sows. <p>Birth weight</p> <ul style="list-style-type: none"> Birth weights of piglets of sows housed in stalls did not differ from those from sows housed in free-access stalls and group pens with trickle feeding but higher than those from sows kept in ESF pens. Girth-tethered sows had piglets with higher birth weights than stalled sows. 	<ul style="list-style-type: none"> Stalled and group penned sows generally had no difference in litter size (Harris et al, 2006; Hulbert and McGlone, 2006; Jansen et al., 2007; Karlen et al., 2007; Salak-Johnson et al., 2007; Chapinal et al., 2010a). However, Seguin et al.(2006) reported higher litter size in group penned sows than stalled sows (10.33 ± 0.20 vs. 9.59 ± 0.34 piglets). For group penned sows, the increase in floor space resulted in the greater litter size (Salak-Johnson et al., 2007). Stalled or group penned sows produced piglets with similar average birth weight and litter birth weight (Harris et al., 2006; Hulbert and McGlone, 2006; Karlen et al., 2007; Salak-Johnson et al., 2007; Chapinal et al., 2010a). However, Seguin et al. (2006) observed higher piglet birth weights in group penned sows than stalled sows (1.58 ± 0.02 vs 1.52 ± 0.03 kg). A higher proportion of piglets born from gilts kept in stalls needed liquid feed after weaning and drank more water at 2 d after weaning (Sorrells et al. 2006) Body weight at 35 d of piglets born from gilts housed in stalls was lower than those born from gilts kept in group pens (Sorrells et al. 2006) No differences in salivary cortisol and immune responses of piglets born from gilts reared in stalls or group pens (Sorrells et al., 2006)

Running Heading: *Updated Review of Gestation Sow Housing Literature*

Review: Updated scientific evidence on the welfare of gestating sows kept in different housing systems

John J. McGlone¹, PAS, ACAWS

Laboratory of Animal Behavior, Physiology and Welfare², Department of Animal and Food Sciences, Texas Tech University, Lubbock, TX 79409-2141

Correspondence:

John J. McGlone, PhD
Professor and Institutional Official
Animal and Food Sciences Department
Texas Tech University
Lubbock, TX 79409-2141
phone: 806-742-2805, ext. 246
fax: 806-742-4003
john.mcglone@ttu.edu

¹ Correspondence: john.mcglone@ttu.edu.

² <http://www.depts.ttu.edu/animalwelfare/>

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ABSTRACT

Gestation sow housing is a contemporary animal welfare issue with legislative actions in the United States to ban individual gestation sow systems. This review sought to summarize the scientific literature since earlier reviews were published in 2004 and 2005. Seventeen papers comparing effect of housing systems on the welfare of gestating sows were published from 2005 to 2012. Stalls/crates, tether housing, and group pens including conventional group pens, loose-house pens, electronic sow feeders (ESF) pens, and hoop barns were reported. The majority of recent findings were similar to the previous conclusions from papers and reviews. Cortisol concentrations were not different between stalled and group penned sows but were higher shortly after mixing in concert with increased sow aggression and skin lesions. The effects of gestation housing system on neutrophil:lymphocyte ratio was still mixed. In the recent literature, stereotypies were greater among stalled sows compared with group penned sows which may reflect a change in sow genetics since the basic housing systems have not changed. Recent papers indicated more sitting/standing inactive, leg and claw problems, and higher farrowing rate (in some studies) among stalled sows. Other studies reported more lying down among group penned sows, and no differences in other reproductive and productivity measures between stalled and group penned sows. Weaning-to-estrus intervals were similar between stalled and group penned sows in contrast to previous reviews that observed a shorter interval among stalled compared with grouped sows. In conclusion, recent papers found similar productivity, physiology health and behavior among individually or grouped sows during gestation.

Key words: Pig, Sow, Gestation housing, Welfare

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INTRODUCTION

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Gestation sow housing is a social issue in Europe, North America, Australia and New Zealand. The primary concern is about the welfare of pregnant sows kept in individual gestation crates (also called stalls). The gestation crate does not allow the sow to turn around or make normal postural adjustments. However, the gestation crate is the most common system used in the United States because it minimizes space needs and provides a means to individually feed and care for pregnant sows. Tether housing and crates or stalls for individual sows have been perceived as housing systems that cause poor welfare. Therefore, European countries and several states (FL, CA, AZ, OR, CO, RI, at least) have banned or are phasing out gestation crates. Retailers (grocery and restaurant) have made public statements that they will preferentially buy pork from farms that do not use gestation crates. Still, the industry defends the gestation crate as a viable sow housing system.

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Two reviews of the scientific literature about the welfare of pregnant sows were published in 2004 and 2005 (McGlone et al., 2004; Rhodes et al., 2005). In the past 8 yr more research has been published that sought to compare the welfare of pregnant sows in individual gestation crates and group pens. The objectives of this review were (a) to summarize the current scientific literature on the welfare of gestation sow housing systems and (b) to determine if the conclusions of the recent literature differ from the conclusions of the previous reviews. Finally, the current status of the welfare of pregnant sows in housing systems is presented based on the newer scientific literature.

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SYSTEMS REVIEWED

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The “control” system by which other systems are compared is the gestation stall (also called crate). This is the control or standard system because at this time, in North America, it

51 is the most common system to keep pregnant sows. Any change away from the crate will
52 incur an economic cost to pork producers and ultimately the consumer. The industry and
53 consumers should know if this seemingly inevitable economic cost is associated with better,
54 the worse or the same sow welfare. While a plethora of systems can be found in which to
55 keep pregnant sows, only a few have generated sufficient scientific literature in which
56 comparisons can be made. These group-housing systems include the (a) group penning with
57 or without individual feeding stalls, and (b) Electronic sow feeders (ESF). Other systems
58 included in the earlier reviews (McGlone et al., 2004; Rhodes et al., 2005) from which there
59 was insufficient new literature were the outdoor system, neck or girth tethers, turn-around
60 stalls, and the Hurnik-Morris system. Because only one paper investigated girth tethers and
61 only two papers examined loose-housing in hoop barns, these system will be mentioned but
62 not highlighted.

63 The scope of this updated literature review is to compare individual with group
64 keeping systems for pregnant sows. Papers have been published with single systems or in
65 ways that ask specific questions about sow preferences or other questions about sow
66 behavior, physiology or health. These papers were not considered here because they did not
67 compare sow keeping systems.

68 Group housing systems are more accepted by some people because as they allow the
69 animals to express social behaviors and sows can turn around. However, group pens also pose
70 welfare problems due to fighting of sows to compete for limited resources and in the
71 establishment of a social hierarchy (Spoolder et al., 2009). Adopting a housing system that is
72 good for the overall welfare of the sows should rely on scientific research results that cover
73 several relevant welfare indicators such as behavior, physiology, health, reproduction, and
74 productivity (CAST, 2009).

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76 MEASURES OF SOW WELFARE

77 Multiple measures of sow welfare should be used in any evaluation of
78 housing/penning systems. For this review, as with past reviews, three types of measures were
79 considered to be direct or indirect measures of sow welfare. These categories include (a)
80 physiology, (b) behavior, and (c) health, reproductive performance and productivity. The
81 categories could be split or merged, however, given that relatively few papers collected all
82 measures.

83 Measures of physiology focused on the stress hormone cortisol (which may rise
84 during stress) and immune measures (which may increase or decrease during stress; Salak-
85 Johnson and McGlone, 2007). Other measures of physiology like heart and respiratory rates
86 were not often measured in the more recent literature.

87 Measures of behavior include maintenance behaviors (sitting, standing, lying, feeding,
88 drinking) and various forms of oral-nasal-facial (ONF) behaviors, including stereotyped
89 behaviors. One particular type of ONF behavior called “stereotypies” is thought by some to
90 be critical measures of sow welfare and thus was summarized. Because of the difficulty of
91 defining which ONF behaviors are and are not “stereotypies, this review considered all ONF
92 behaviors. However, an alternative views relates to expression of more ONF behaviors as a
93 welfare problem (Damm et al., 2005).

94 The category of measures including health, reproduction and productivity is very
95 broad. Health measures that were tied to a putative stress response were included in
96 measures of physiology. Measures of reproductive health and productivity are connected and
97 logically can be in one category. Health also includes bone and foot and leg health and body
98 and vulva lesions.

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METHODS

101 The scientific literature was searched electronically. Agricola, Pubmed, and Google
102 Scholar were searched from the period of Jan 1, 2005 through August 1, 2012. Keywords
103 included sow and/or pig, housing or penning. In addition, journals known to contain papers
104 on pig biology were searched including The Journal of Animal Science, The Professional
105 Animal Scientist, Livestock Science, Applied Animal Behaviour Science, Animal, Animal
106 Welfare, Journal of Applied Animal Welfare Science and Journal of Swine Health and
107 Production.

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109

FINDINGS

110 Results from 17 publications from 2005 to 2012 comparing housing systems for
111 gestating sows in a variety of aspects relating to welfare were summarized in each animal
112 welfare category. Methodologies used in the reviewed studies are presented in Table 1.
113 Details of the findings by measure are provided in Tables 2 to 6.

114

Physiology

116 Blood or salivary cortisol concentrations have been used to determine stress among
117 gestating sows in housing systems. Comparing stall- and group-kept sows, most authors
118 found no differences in cortisol concentrations. The recent literature confirms the earlier
119 reviews that sows in stalls or group pens may equally adapt to the environments by mid
120 gestation. Group-kept sows are often mixed, and this results in fighting and an elevation in
121 cortisol (Jansen et al., 2007). Associations among mixing of grouped sows, aggressive
122 interactions, and cortisol have been investigated in studies dealing with grouping of sows in a
123 single system but not including a comparison of sows in crates and group pens. Therefore,
124 these papers were not included in this review. After the social hierarchy was established, no
125 differences were observed in cortisol concentrations between crated and group penned sows

126 (Hulbert and McGlone, 2006; Karlen et al., 2007). Cortisol was also elevated when group-
127 penned gestating sows were moved to farrowing crates compared with sows crated during
128 gestation and moved to farrowing crates (Sorrells et al., 2007). The restricted movement and
129 individual housing of the farrowing crate may cause the cortisol rise among previously group
130 housed sows.

131 For stress-related immune measures, there were inconsistent results. Karlen et al.
132 (2007) found higher neutrophil:lymphocyte ratios measured at 15 wk of gestation among
133 stalled sows compared with group penned sows. One could argue that with advancing
134 pregnancy, the crate may become more cramped and therefore elicit a stress response. In
135 contrast, Hulbert and McGlone (2006) did not find differences in neutrophil:lymphocyte
136 ratios, % neutrophil phagocytosis, and neutrophil chemotaxis measured at mid gestation
137 between individually crated and group housed sows; however, they did not collect samples
138 over time of advancing pregnancy.

139

140 **Behavior**

141 Some authors argue ONF behavior should include feeding and drinking behaviors
142 (McGlone et al., 2004) while others argue ONF should not include feeding and drinking oral
143 behaviors (Damm et al.(2005). Setting this argument aside, one class of ONF behaviors --
144 the stereotypies directed to objects such as bars and feeders -- were greater among stalled
145 sows compared with group penned sows (Karlen et al., 2007). These recent findings are
146 consistent with the results from the previous reviews.

147 Sitting or standing inactive for long periods may indicate poor welfare according to
148 both the previous reviews and the current literature. Lying, in the opposite way, may reflect
149 good welfare as shown if the lying behaviors in group penned sows increased. Hulbert and
150 McGlone (2006) found no difference in behavior for sows kept in stalls or group pens.

151 Findings about aggressive behaviors were consistent in the recent literature that
152 evaluated group housing. Sows show an increase in aggressive interactions after weaning or
153 mixing after breeding (Jansen et al., 2007). Seguin et al. (2006) and Salak-Johnson et al.
154 (2007) investigated the effects of space allowance on lesion scores but not on aggressive
155 behavior; nor did they have a direct comparison with individually-kept sows. Clearly, mixing
156 sows into new social groups will elicit aggression that will resolve itself over time. And
157 smaller spaces can lead to increased lesions among group-housed sows, possibly due to
158 increased aggression with smaller floor space (but this was not directly studied).

159

160 **Health, Reproductive Performance & Productivity**

161 Body lesions (mostly resulting from fighting especially shortly after mixing) and
162 locomotory problems have been investigated to determine welfare of sows housed in different
163 systems. Concerning foot and leg problems, results were mixed. Conventional group penned
164 sows and those kept in ESF had more lameness scores and claw lesions than stalled sows as
165 long as there was no bedding (Harris et al., 2006; Anil et al., 2007). In contrast, Karlen et al.
166 (2007) reported more lameness among stalled sows than group penned sows provided deep
167 bedding. However, in an epidemiological study, Ryan et al. (2010), observed similar lameness
168 scores and joint pathologies between sows housed in stalls and loose-housed pens where
169 bedding was provided. Therefore, lameness may be more a function of the absence of
170 bedding rather than housing system.

171 The previous reviews concluded that weaning-to-estrus interval in gestating sows
172 reared in stalls was shorter than those kept in group pens. However, from the current results,
173 weaning-to-estrus interval and also weaning-to-service interval were not different between
174 stalled and group penned sows (Table 5). In one study, farrowing rates were reduced in group
175 penned sows compared to stalled sows (Kareln et al., 2007). However, Hulbert and McGlone

176 (2006) did not find a difference in reproduction between crated and grouped sows. Other
177 reproductive parameters also indicate no difference due to housing. On the whole,
178 reproductive performance was similar for sows in group pens and individual crates in the
179 current literature.

180 Several reports showed no difference in litter size for sows housed in stalls compared
181 with any type of group pens (Harris et al., 2006; Hulbert and McGlone, 2006; Jansen et al.,
182 2007; Karlen et al., 2007; Salak-Johnson et al., 2007; Chapinal et al., 2010a). However, one
183 study found greater litter size among group penned sows compared with individually crated
184 sows (Seguin et al., 2006).

185 Sorrells et al.(2006) studied prenatal stress in piglets born from gilts housed in stalls
186 or pens. Piglets from individually crated mothers were lighter and required more
187 supplemental feeding than piglets whose mothers were group housed. These findings may not
188 be directly relevant to the welfare of gestating sows but may relate to the welfare in the entire
189 system since the welfare of piglets may be impacted by gestation housing system.

190

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CONCLUSIONS

192 Cortisol concentrations may be used as a physiological sign of stress. Cortisol
193 concentrations were higher among group penned sows shortly after mixing (Jansen et al.,
194 2007). However, cortisol concentrations were not different between stalled and group-
195 penned sows in mid gestation. Differences in immune measures were not detected between
196 crated and penned sows. Physiological measures, on the whole, were not different between
197 individually crated and group-kept pregnant gilts and sows. This is consistent with the earlier
198 reviews.

199 Overall ONF behaviors did not differ among sows in group or individual systems. In
200 contrast, stereotypies were higher among stalled sows than group penned sows in one paper

201 (Karlen et al., 2007) but not another (Hulbert and McGlone, 2006). Excessive sitting and
202 standing inactive may indicate poor welfare. More sitting and/or standing inactive were
203 reported in stalled sows compared to group housed sows (Munsterhjelm et al., 2008; Weng et al.,
204 2009), however, Hulbert and McGlone (2006) did not find this.

205 Aggression commonly occurs in group penned sows particularly shortly after mixing
206 and during feeding. This aggression leads to body or vulva lesions (Jansen et al., 2007; Salak-
207 Johnson et al., 2007; Chapinal et al., 2010a; Chapinal et al., 2010b).

208 Because the housing systems have not changed, it is possible that the selection for
209 improved reproductive performance or other traits has resulted in sows that express more
210 stereotypies when individually crated. My laboratory has recent unpublished work using the
211 same model as (Hulbert and McGlone (2006) but with a more modern genetic line and in the
212 recent work, sow aggression was greater among group-housed sows than individually crated
213 sows. However, one cannot draw this conclusion on the basis of just a few recent papers or
214 work in progress. However, it is an interesting hypothesis that recent intensive genetic
215 selection may have changed the behavior of pregnant sows perhaps with increased
216 aggressive, sitting and ONF behaviors.

217 Both recent studies and the earlier reviews found that leg and foot problems had a
218 greater incidence in group penned sows than crated sows (McGlone et al., 2004; Harris et al.,
219 2006; Anil et al., 2007). However, lameness issues may be more a function of bedding (or
220 lack of bedding) than penning system (Karlen et al., 2007).

221 In the recent literature, no differences were observed in weaning-to-estrus interval
222 among stalled versus group-kept sows. Higher farrowing rates were reported among stalled
223 sows compared to group penned sows in one study (Karlen et al., 2007), but this was not
224 found by Hulbert and McGlone (2006). Other reproductive parameters such as ovulation rate,
225 number of embryos, embryo survival, backfat thickness, and body condition scores were

226 similar among sows kept in stalls or group pens. Most studies indicated no difference in litter
227 size and birth weight of piglets born from sows housed in stalls or group pens. The majority
228 of the current findings from 2005 to 2012 were not different from those in the previous
229 review. On the whole, few physiological, behavioral or health differences were reported
230 between individually crated and group-kept pregnant gilts and sows.

231

232 **Implications**

233 Overall, group penning and individual crating of pregnant sows support about the
234 same level of measurable sow welfare. Grouping has negative consequences such as more
235 body lesions occur due to aggressive behaviors when grouped. Individual crating may cause
236 more stereotyped behaviors of unknown cause or consequence, although this observation was
237 not consistent across studies. A compilation of the recent scientific literature does not draw
238 one to a different conclusion than the literature summarized in 2004 and 2005.
239 Improvements in the welfare of sows are possible in each pregnant sow keeping system.

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Table 1. Methodologies in reviewed recent literature.

Authors	Animals, parities	Housing systems compared	Space allowance (m ² /sow)	Bedding	Group sizes, replicates	Measures
Chapinal et al. (2010a)	Landrace x Large White; parities 1-9	Stall (S) group pen (P) unprotected ESF group pen (ESF)	1.29 (S) 2.76 (P) 2.32 (ESF)	No	20 stalled sows, 2 group pens of 10 sows, and an ESF pen of 20 sows x 3 replicates	<ul style="list-style-type: none"> • Behavior (week 1-2 and then every week) • Haptoglobin and Pig-MAP (week 11-13 and 16-18) • Reproduction • Productivity • Lameness and injury
Chapinal et al. (2010b)	Landrace x Large White; parities 1-9	Group pen (P) ESF group pen (ESF)	2.76 (P) 2.32 (ESF)	No	2 group pens of 10 sows and an ESF pen of 20 sows x 3 replicates	<ul style="list-style-type: none"> • Aggressive behavior
Ryan et al. (2010)	Cull sows in 8-9 parities (studied at the abattoir)	Stall, loose-house	NA	Yes (straw for loose-house)	4,120 stalled sows from 5 farms, 2,900 loose-housed sows from 2 farms (group size of 100)	<ul style="list-style-type: none"> • Lameness score • Joint pathologies
van der Staay et al.(2010)	Great Yorkshire/Large White x Dutch Landrace; parities 2-13	Tethering (T), loose house (L)	2.2 (L)	No	59 loose-housed sows (65-130 sows/pen), 70 tethered sows	<ul style="list-style-type: none"> • Plasma cortisol • Weights of adrenal, pituitary, and spleen • mRNA of PrP and β-globulin in brain
Weng et al.(2009)	Landrace x Yorkshire gilts	Stall S) group pen (P) ESF group pen (ESF)	1.41(S) 1.80 (P) NA (ESF)	No	16 stalled sows, 16 group penned sows (5 sows/pen), 32 ESF sows	<ul style="list-style-type: none"> • Behavior at 8 physiological stages from estrus to dry

Munsterhjelm et al.(2008)	Yorkshire (64%), Yorkshire x Finnish Landrace (36%), averaged parities 2.4	Stall, group pen	1.44 (S) 5.10 (P)	Yes (deep litter for pen)	240 stalled sows, 240 group penned sows (12 pens of 20 sows)	<ul style="list-style-type: none"> • Behavior (day 27 after weaning) • Reproduction • Productivity
van Wettere et al.(2008)	Purebred maternal (Large White)/terminal (Duroc)	Stall, group pen	1.36 (S) 2.40 (P)	No	24 stalled sows, 4 group pens of 6 sows x 3 mixing treatments	<ul style="list-style-type: none"> • Reproduction
Anil et al.(2007)	Gilts and sows; parities 0-8	Stall, ESF group pen,	1.20 (S) NA (ESF)	No	82 stalled sows, 102 group penned sows (no group size mentioned)	<ul style="list-style-type: none"> • Claw lesions measured at day 110 of gestation
Jansen et al.(2007)	Landrace and Yorkshire; parities 0, 1, 3	Stall, group pen	NA (S) 2.10 (P)	No	48 stalled sows, 48 group penned sows (mixed with other sows in 4 pens to form a group of 50)	<ul style="list-style-type: none"> • Behavior (0-3 d after mixing) • Lesion scores (+1, -1 d of mixing) • Salivary cortisol (+1, -1 d of mixing) • Reproduction
Karlen et al.(2007)	Landrace x Large White; parities ≥ 1	Stall, group pen	1.26 (S) 2.30 (P)	Yes (deep rice hull for group pen)	640 sows in total, group size of 85	<ul style="list-style-type: none"> • Behavior (week 1, 9 of gestation) • Salivary cortisol (day 5, week 9 of gestation) • Hematology and lymphocyte proliferation (week 15 of gestation) • Reproduction
Lammers et al.(2007)	25% Hampshire x 50% Yorkshire x 25% Landrace;	Stall (S), hoop barns (H)	1.26 (S) 3.44 (H)	Yes (deep cornstalks for hoop)	552 stalled sows, 405 group penned in hoop barns (32	<ul style="list-style-type: none"> • Productivity

	parities 0-2			barns)	sows/pen, 2 pens/barn, 2 barns)	
Salak-Johnson et al.(2007)	Sows (PIC) in parities ≥ 1	Stall, group pen	1.29 (S) 1.40, 2.30, and 3.30 (P)	No	51 stalled sows, 166 group penned sows (group size of 5)	<ul style="list-style-type: none"> • Productivity • Lesion scores (every 3 d for the first 2 weeks, then every week of gestation)
Sorrells et al.(2007)	Landrace x Yorkshire gilts	Stall, group pen	1.32 (S) 2.34 (P)	No	16 stalled gilts, 8 group pens of 4 gilts	<ul style="list-style-type: none"> • Cortisol , cytokines, and acute phase proteins during gestation and after farrowing
Harris et al.(2006)	Landrace x Yorkshire gilts	Stall, group pen	1.35 (S) 2.40 (P)	No	16 stalled gilts, 8 group pens of 4 gilts	<ul style="list-style-type: none"> • Behavior (week 4, 6, 9, and 13 of gestation) • Lesion scores (every 2 weeks) • Productivity
Hulbert and McGlone (2006)	Camborough 22 gilts	Stall, group pen	1.33 (S) 1.28 (S)	No	80 stalled gilts, 80 group penned gilts	<ul style="list-style-type: none"> • Behavior (50-60 d of gestation) • Cortisol (50-60 d of gestation) • Hematology and immune (50-60 d of gestation) • Reproduction • Productivity
Seguin et al.(2006)	Yorkshire; parities 2.8	Stall, group pen	2.00 (S) 2.30, 2.80, and 3.20 (P)	No	98 stalled sows, 9 small group penned sows (group size of 11-19), 6 large group penned sows (group size of 22-31)	<ul style="list-style-type: none"> • Lesion scores (+1,-1 d of mixing, then every week for 5 weeks) • Productivity
Sorrells et al.(2006)	Landrace x Yorkshire gilts	Stall, group pen	1.35 (S) 2.41 (P)	No	16 stalled gilts, 8 group pens of 4 gilts	<ul style="list-style-type: none"> • Behavior (isolation test in piglets)

						<ul style="list-style-type: none">• Cortisol, acute phase proteins, IgG, and TNF-α in piglets
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For Peer Review

Table 2. Effects of housing on physiology of gestating sows

Findings from the previous reviews in 2004 (McGlone et al., 2004) and Rhodes et al.(2005)	Findings from 2005-2012
<p>Cortisol</p> <ul style="list-style-type: none"> • Circulating cortisol concentrations of stalled and group penned sows did not differ. However, the concentrations in tethered sows were greater compared to those in stalled or group penned sows. <p>Immune responses</p> <ul style="list-style-type: none"> • Housing did not influence neutrophil: lymphocyte ratio, immunoglobulin concentrations, antibody response against sheep red blood cell antigens, and natural killer cell activity. <p>Cardiovascular functions</p> <ul style="list-style-type: none"> • There was no information comparing cardiovascular response of sows in different housing systems. 	<ul style="list-style-type: none"> • Tethered sows had higher plasma cortisol than loose-housed sows (van der Staay et al., 2010). No variation in concentrations of plasma cortisol measured during 50-60 days of gestation between sows housed in crates and group pens (Hulbert and McGlone, 2006). • Salivary cortisol concentrations measured at 1 and 9 weeks of gestation were not different between stalled and group penned sows (Karlen et al., 2007). However, Jansen et al. (2007) found significantly higher salivary cortisol concentrations in group penned sows the day of relocation compared to prior moving. In addition, group penned gilts had higher salivary cortisol levels shortly after moving to farrowing crates compared to stalled gilts (Sorrells et al., 2007). • There were no differences in neutrophil: lymphocyte ratio, % neutrophil phagocytosis, and neutrophil chemotaxis between crated and group penned sows (Hulbert and McGlone, 2006). • Stalled sows had higher neutrophil: lymphocyte ratio than group penned sows (Karlen et al., 2007). • No differences in cytokines m RNA expressions and acute phase proteins between stalled and group penned gilts (Sorrells et al., 2007) • Stalled and group penned sows had similar heart rates at rest and during activities (Harris et al., 2006).

Table 3. Effects of housing on behavior of gestating sows

Findings from the previous reviews in 2004 (McGlone et al., 2004) and Rhodes et al.(2005)	Findings from 2005-2012
<p>Oral-nasal-facial (ONF) behaviors and stereotypies</p> <ul style="list-style-type: none"> • ONF behaviors in stalled and group penned sows were similar. Tethered sows might show higher or lower ONF behavior depending on experimental designs. Sows housed in group pens expressed less time spent for stereotypies than those housed in stalls. <p>Locomotory and postural behaviors</p> <ul style="list-style-type: none"> • Gilts kept in turn-around stalls had more standing activity than stalled gilts. An increase in space allowance reduced standing and sitting inactive of sows in group pens. Group pen sows changed more postures than stalled sows in farrowing stalls and more restless at parturition. 	<ul style="list-style-type: none"> • Stalled and group penned sows had no difference in percentage of time spent for ONF behaviors (Hulbert and McGlone, 2006; Munsterhjelm et al., 2008). However, Chapinal et al.(2010a) reported that stalled sows spent higher proportion of time for ONF behaviors than group penned sows. Percentages of time spent for stereotyped interactions with bars and feeders were greater in stalled sows than group penned sows which was contrast to the percentage of time spent for stereotyped interactions with floor (Karlen et al., 2006). • Munsterhjelm et al.(2008) found that stalled sows engaged more in standing inactive which was an indicator of poor welfare than group penned sows. More standing, sitting, rooting, and drinking were also observed in stalled sows than group penned sows and sows housed in Electronic Sow Feeding (ESF) system (Weng et al., 2009). ESF sows had higher time spent for lying and less time spent for rooting and drinking (Weng et al., 2009). This was consistent with the results of Chapinal et al. (2010a) indicating more lying in ESF sows than stalled sows and group penned sows with trickle feeding system. Karlen et al. (2007) reported more lying and less standing/walking at week 9 of gestation among stalled sows than group penned sows. However, Hulbert and McGlone (2006) did not find any difference in time budgets for lying, sitting, and standing/walking in crated and group penned sows.

<p>Social behaviors</p> <ul style="list-style-type: none">• Agonistic behavior was higher in group penned sows particularly during mixing and feeding compared to stalled and tethered sows. Increased space allowance resulted in a decreased agonistic behavior and social interactions among group penned sows.	<ul style="list-style-type: none">• Total number of active and passive aggressive encounters was greater in group penned sows than stalled sows and during feeding than during after mixing (Jansen et al., 2007). When 2 types of group pens were compared, ESF penned sows had higher frequency of aggressive behavior than conventional group penned sows (Chapinal et al., 2010b). Karlen et al.(2007) also noted the decrease of fighting in group penned sows at 9 weeks of gestation compared to that in the first week. Results revealed by Hulbert and McGlone (2006) indicate no difference in agonistic behavior of crated sows and group penned sows at 50-60 days of gestation.
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For Peer Review

Table 4. Effects of housing on health of gestating sows

Findings from the previous reviews in 2004 (McGlone et al., 2004) and Rhodes et al.(2005)	Findings from 2005-2012
<p>Vulva biting</p> <ul style="list-style-type: none"> • Vulva injuries related to biting were more frequent in ESF sows than other types of group housing systems. There was no prevalence of vulva biting in stalled sows and tethered sows. <p>Body lesion scores</p> <ul style="list-style-type: none"> • Group penned sows had 3 times higher percentage of body lesions caused by fighting compared to stalled sows. Provision of roughage reduced a risk of developing body lesions in group penned sows. <p>Locomotory problems</p> <ul style="list-style-type: none"> • Incidence of claw lesions was twice as high among loose-housed sows than stalled sows and was also more common than tethered sows. Sows housed in group pens with deep bedding were found to have higher claw lesions than stalled and tethered sows. Without bedding, lameness incidence was greater in ESF and group penned sows compared to 	<ul style="list-style-type: none"> • Higher numbers of sows developed vulva biting in ESF and group penned sows compared to stalled sows (Chapinal et al., 2010). However, Harris et al. (2006) did not detect difference in vulva lesion scores between stalled and group penned sows. • Group penned sows had higher lesion scores than stalled sows after mixing and these scores correlated with the total number of agonistic interactions (Jansen et al., 2007). Salak-Johnson et al.(2007) noticed a decrease in space allowance (1.4 vs. 2.3 and 3.3 m²) leading to higher lesion scores in group penned sows. However, a study by Seguin et al.(2006) indicated that there was no difference in lesion scores of sows provided space allowance of 2.3, 2.8, and 3.2 m². The study by Hulbert and McGlone (2006) showed no dissimilarity in lesion scores measured at mid-gestation between crated sows and group penned sows. • Group penned gilts lacking bedding had more foot and leg problems investigated at 13 weeks of gestation than stalled gilts (Harris et al., 2006). Karlen et al.(2007) reported higher lameness scores measured at 9 and 13 weeks of gestation among stalled sows than group penned sows provided deep bedding. Comparing ESF with stall housing, Anil et al.(2007) discovered higher proportion of sows kept in ESF developing claw lesions. However, based on the study of Ryan et al.(2010), lameness scores and joint pathology of culled sows previously

stalled and free –access stalled sows.	housed in stalls or loose-housed pens were not different
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For Peer Review

Table 5. Effects of housing on reproductive performance of gestating sows

Findings from the previous reviews in 2004 (McGlone et al., 2004) and Rhodes et al.(2005)	Findings from 2005-2012
<p>Weaning-to-estrus interval</p> <ul style="list-style-type: none"> Sows housed in stalls had shorter weaning-to-estrus interval than those housed in group pens. Group penned sows had similar estrus detection rate and estrus duration. <p>Farrowing rate</p> <ul style="list-style-type: none"> farrowing rate in stalled sows was higher than group penned sows. Tethered sows had lower farrowing rate than stalled and group penned sows. There was no difference in farrowing rates of outdoor reared sows compared to indoor stalled sows. Stalled sows had greater farrowing rate than loose-housed sows during summer. 	<ul style="list-style-type: none"> Munsterhjelm et al.(2008) observed no difference in weaning-to-estrus interval between stalled and group penned sows. This was consistent with a report by Jansen et al.(2007). Also, weaning-to-service did not differ between stalled and group penned sows (Harris et al., 2006; Munsterhjelm et al., 2008). In contrast, Lammers et al.(2007) noticed shorter weaning-to-estrus interval among stalled sows than group penned sows. Stalled sows had higher farrowing rate than group penned sows (Karlen et al., 2007). In contrary, Hulbert and McGlone (2006) found no variation in farrowing rates of sows housed in stall and group pens. van Wettere et al.(2008) also detected a similar in ovulation rate, number of embryos, and embryo survival in gilts kept in stalls and group pens. Body condition scores (BCS) evaluated before and after entering gestation did not differ in stalled and group penned sows (Seguin et al., 2006). Body weight and backfat thickness were also not different between stalled and group penned sows (Harris et al., 2006; Hulbert and McGlone, 2006; Chapinal et al., 2010a). Space allowance positively affected body weight, BCS, and backfat thickness (Salak-Johnson et al., 2007). There was a similarity in body weight at farrowing and weaning and backfat thickness at

	breeding, farrowing, and weaning in sows housed in crates or group pens (Hulbert and McGlone, 2006).
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For Peer Review

Table 6. Effects of housing during gestation on productivity of sows and behavior and physiology of offspring

Findings from the previous reviews in 2004 (McGlone et al., 2004) and Rhodes et al.(2005)	Findings from 2005-2012
<p>Litter size</p> <ul style="list-style-type: none"> Sows housed in stalls, free-access stalls, ESF pen, and group pens with trickle feeding had a similar litter sizes. However, tethered sows had smaller litter size than stalled and group penned sows. <p>Birth weight</p> <ul style="list-style-type: none"> Birth weights of piglets of sows housed in stalls did not differ from those from sows housed in free-access stalls and group pens with trickle feeding but higher than those from sows kept in ESF pens. Girth-tethered sows had piglets with higher birth weights than stalled sows. 	<ul style="list-style-type: none"> Stalled and group penned sows generally had no difference in litter size (Harris et al, 2006; Hulbert and McGlone, 2006; Jansen et al., 2007; Karlen et al., 2007; Salak-Johnson et al., 2007; Chapinal et al., 2010a). However, Seguin et al.(2006) reported higher litter size in group penned sows than stalled sows (10.33 ± 0.20 vs. 9.59 ± 0.34 piglets). For group penned sows, the increase in floor space resulted in the greater litter size (Salak-Johnson et al., 2007). Stalled or group penned sows produced piglets with similar average birth weight and litter birth weight (Harris et al., 2006; Hulbert and McGlone, 2006; Karlen et al., 2007; Salak-Johnson et al., 2007; Chapinal et al., 2010a). However, Seguin et al. (2006) observed higher piglet birth weights in group penned sows than stalled sows (1.58 ± 0.02 vs 1.52 ± 0.03 kg). A higher proportion of piglets born from gilts kept in stalls needed liquid feed after weaning and drank more water at 2 d after weaning (Sorrells et al. 2006) Body weight at 35 d of piglets born from gilts housed in stalls was lower than those born from gilts kept in group pens (Sorrells et al. 2006) No differences in salivary cortisol and immune responses of piglets born from gilts reared in stalls or group pens (Sorrells et al., 2006)