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1 **Consistency is key: interactions of current and previous farrowing system on litter size**
2 **and piglet mortality**

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9 Short title: Farrowing system consistency and sow performance

10 **Abstract**

11 Global interest in alternative indoor farrowing systems to standard crating is
12 increasing, leading to a growing number of farms utilising such systems alongside
13 standard crates. There is evidence that interchanging sows between different
14 farrowing systems affects maternal behaviour, whilst the subsequent effect of this on
15 piglet mortality is unknown. The current study hypothesised that second parity piglet
16 mortality would be higher if a sow farrowed in a different farrowing system to that of
17 her first parity. Retrospective farm performance records were used from 753 sows
18 during their first and second parities. Sows farrowed in either standard crates
19 (crates), temporary crates (360s) or straw-bedded pens (pens), with mortality
20 recorded as occurring either pre- or post-processing, whilst inter- and intra-parity sow
21 consistency in performance were also investigated. Overall, total piglet mortality
22 reduced from the first to the second parity, being significantly higher in the crates and
23 higher in the 360s during the first or second parity, respectively. In the second parity,
24 an interaction of the current and previous farrowing systems resulted in the lowest

25 incidence of crushing for sows housed in the same system as their first parity for the
26 crates and pens, but not the 360s. Post-processing mortality was significantly higher
27 in the crates if a sow previously farrowed in the 360s and vice versa. Sows which
28 previously farrowed in a pen had a significantly larger litter size and lower pre-
29 processing mortality from crushing in their second parity than sows previously
30 housed in the crates or the 360s. No inter-parity consistency of sow performance was
31 found, whilst intra-parity consistency was found in the first but not second parity. In
32 conclusion, returning sows to the same farrowing system appears to reduce piglet
33 mortality, whilst farrowing in a pen during the first parity significantly increased
34 second parity litter size without increasing piglet mortality.

35 **Keywords:** sow performance, sow experience, maternal behaviour, free farrowing,
36 temporary crating

37 **Implications**

38 When trialling new farrowing systems, both experimentally and commercially, the
39 previous experience of the sows is often overlooked. However, as sow behaviour at
40 farrowing affects piglet mortality, is mediated by the environment and is believed to
41 develop over successive parities, it is likely that a change of farrowing system would
42 disrupt maternal behaviour and subsequently increase piglet mortality. This topic is
43 especially important as more farmers consider the uptake of higher welfare farrowing
44 systems, as piglet mortality may initially increase until sows adapt to, and preferably
45 return to, the same farrowing system throughout their reproductive life.

46 **Introduction**

47 Consumers prefer livestock to have freedom of movement and the opportunity to
48 perform natural behaviours (Lassen *et al.*, 2006), which has contributed to the

49 increase of outdoor breeding sows in the UK from 19% to 42% of the national herd
50 size in the past two decades (Farm Animal Welfare Council, 1996; Royal Society for
51 the Prevention of Cruelty to Animals, 2016). Globally, indoor pork producers are
52 increasingly interested in transitioning to less restrictive systems, particularly for
53 farrowing and lactation (Farm Animal Welfare Committee, 2015). However, piglet
54 mortality is often considered to be higher in alternative farrowing systems (Hales *et*
55 *al.*, 2014), although this is not always the case (KilBride *et al.*, 2012). Furthermore, a
56 recent Opinion of the UK Farm Animal Welfare Committee recommended further
57 research to reduce piglet mortality in free farrowing systems before the abolition of
58 farrowing crates in the UK can be considered (FAWC, 2015).

59 Research has developed multiple indoor alternatives to the farrowing crate, some of
60 which are already in commercial use (e.g. PigSAFE pen, Edwards *et al.*, 2012;
61 SWAP pen, Hales *et al.*, 2015). However, alternative farrowing systems are
62 sometimes used alongside more traditional farrowing crates within the same herd,
63 causing sows to be housed interchangeably between farrowing systems. This can
64 occur acutely whilst a farm transitions to a new farrowing system, or chronically as
65 multiple farrowing systems are used long term. Whilst some higher-welfare
66 Assurance Scheme standards recommend continually housing sows in the same
67 farrowing system to avoid negatively impacting sow welfare (RSPCA, 2016), very
68 little research has investigated the effect that a change in farrowing system has on
69 the sow.

70 Extensive research has shown the immediate farrowing environment to affect the
71 behaviour and physiology of the sow during farrowing and lactation (e.g. Cronin and
72 van Amerongen, 1991; Arey and Sancha, 1996; Yun *et al.*, 2013). Consequently, the
73 farrowing system not only affects piglet mortality directly via the level of physical

74 protection from accidental crushing, but also indirectly by influencing the maternal
75 care that a sow will provide. Indeed, proficiency of sow behaviour is considered even
76 more critical for piglet survival in less restrictive systems, where physical and human
77 intervention are often more difficult to implement (Arey, 1997). Sow productivity is
78 considered an individually stable trait, measurable via piglet survival in early lactation
79 (Wechsler and Hegglin, 1997; Su *et al.*, 2007). However, sow maternal behaviour
80 may develop over successive parities, as the previous farrowing environment
81 influences subsequent maternal behaviour (Jarvis *et al.*, 2001; Thodberg *et al.*,
82 2002a and 2002b), meaning sow welfare and productivity may be optimised by
83 routinely returning individuals to the same farrowing system.

84 The aim of the current study was to determine if the farrowing system used during
85 the first and second parity affected current and future piglet mortality. Individual
86 consistency in sow performance between different phases of the same parity and
87 across parities was also explored. It was hypothesised that second parity sows which
88 return to the same farrowing system would have lower piglet mortality than sows
89 which changed farrowing systems, and that mortality would be particularly high for
90 sows which change from a restrictive to less restrictive farrowing system.

91 **Materials and methods**

92 *Animals and dry sow management*

93 Data were collected on a commercial pig breeding unit in the north east of England.
94 The farm consisted of 1 300 Camborough (Genus PIC, Basingstoke) breeding gilts
95 and sows, bred with Hampshire semen. During gestation, all animals were kept in
96 straw pens in groups according to age, for gilts, or by size for multiparous sows, and
97 were fed via dump-feeders once daily with approx. 3kg of pelleted feed per sow per

98 day (gilts = 12.42% CP, 12.52 DE MJ/Kg ; sows = 11.85% CP, 12.47 DE MJ/Kg).

99 Animals were moved into the farrowing accommodation one week before the
100 expected farrowing date.

101 *Farrowing sow housing and management*

102 During farrowing and lactation, sows were housed in one of three farrowing systems
103 within the same farm: standard farrowing crates (crates), a temporary crate system
104 (360s; 360° Freedom Farrower®, Midland Pig Producers, Burton-on-Trent) or a
105 kennel and run straw-based pen system (pen; see Supplementary Figures S1-S3 for
106 images or www.freefarrowing.org for further information). Data collection was
107 performed as the farm transitioned from using crates to 360s; with 132 crates and
108 zero 360s at the beginning of data collection, and 20 crates and 168 360s by the end
109 of data collection; whilst 62 pens were used throughout the study period.

110 Crates on the farm consisted of two types, in either one of three older buildings or
111 two new PortaPig cabins. The old farrowing crates were 2.65m x 0.60m within a
112 2.70m x 1.90m pen with solid concrete flooring and metal slats to the rear of the pen
113 and contained a 1.40m x 0.60m heat pad to the top right of the pen and covered in
114 wood shavings for old crates only (Figure 1a). The new farrowing crates were 2.50m
115 x 0.60m within a 2.50m x 1.80m fully plastic slatted pen including a 1.20m x 0.40m
116 heat pad centrally located along the pen side adjacent to the central walkway.

117 The 360s were comprised of a stainless steel crate (2.50m x 0.90m when closed,
118 2.50m x 1.60m at sow shoulder height when opened) within a 2.50m x 1.80m pen
119 (Figure 1b). Pens with 360s had plastic slatted flooring with a solid panel containing
120 drainage slots in the sow lying area plus a 1.80m x 0.40m heat pad to one side of the
121 crate. Two parallel vertical bars were positioned at the rear of the crate for additional

122 piglet protection. The 360s crates were closed from sow entry into the farrowing
123 house until approx. ten days post-partum, with handfuls of shredded paper provided
124 on the floor of the 360s crate from two days before expected farrowing and removed
125 at first litter handling (4-16h post-farrowing). Of the 168 360s on the farm by the end
126 of data collection, 120 were located in six PortaPig cabins containing
127 20 farrowing places each. The remaining 48 places were in a converted farrowing
128 house (previously farrowing crates) of three adjoining rooms containing 16 360s each
129 (refer to King *et al.*, *submitted* for additional details of the 360s configuration).

130 Buildings containing crates and 360s were kept at $22 \pm 1^\circ\text{C}$, with the additional heat
131 mat along one side of each pen starting at 36°C and reducing to 30°C by weaning.
132 Room temperature was gradually reduced automatically to $18 \pm 1^\circ\text{C}$ by day ten post-
133 partum and to $16 \pm 1^\circ\text{C}$ by weaning.

134 The pens were in rows of individual units constructed from timber in the 1960s, each
135 consisting of a 2.30m x 1.20m indoor nest area with adjacent 2.30m x 0.70m
136 separate covered piglet creep area and access to a 2.55m x 2.00m outdoor run
137 (Figure 1c). Pens had a solid concrete floor throughout, whilst the nest area
138 contained farrowing rails and piglet protection bars across three sides to reduce
139 piglet crushing risk. The nest area contained 5kg of long straw from sow entry, whilst
140 the creep floor was covered in wood shavings. The pens had no central heating
141 system, however a 400w electric heater was placed at one end of the creep, which
142 was individually switched off three to five days post-partum. Pens were routinely
143 cleaned out weekly with straw and wood shavings replenished. Pre-partum,
144 additional straw or wood shavings were added to nests when required and soiled
145 straw was removed and replenished post-partum.

146 FIGURE 1 NEAR HERE.

147 *Farrowing sow and piglet husbandry*

148 Sows were fed once daily in the morning until all sows in the building had farrowed,
149 after which sows were fed twice a day (15.98% CP, 13.69 DE MJ/Kg). All animals
150 were hand fed, either into a feed trough in both crated systems or onto the nest floor
151 in the pen system. Feed was gradually increased from 2kg to 10kg per sow per day
152 in 1kg increments during lactation. Water was provided *ad libitum*, either from
153 drinkers in the two crated systems or from a floor trough in the outdoor area of the
154 pen system. In accordance with veterinary recommendation, piglets were tail docked,
155 teeth clipped, and injected with 1ml of Gleptosil (Ceva Animal Health Ltd,
156 Amersham) and 0.5ml of Betamox (Norbrook Laboratories Ltd, Newry) within 24
157 hours of birth. Placentae and deceased piglets were removed, and live litter size was
158 equalised for both piglet number and size by cross-fostering piglets of a similar
159 age. Super Dry Klenz powder (A-One Feed Supplements Ltd, Thirsk) was distributed
160 across crates and 360s daily to minimise bacterial infections. A handful of creep feed
161 (Primary Diets, AB Agri Ltd, Peterborough; followed by Flat Deck, A-One Feed
162 Supplements Ltd, Thirsk) was provided once daily on the floor in all systems from
163 approx. ten days of age until weaning. The farm's management routines included
164 piglet cross-fostering throughout lactation as necessary to ensure piglet and litter
165 sizes remained similar.

166 *Experimental design*

167 Sows were housed in one of the three described farrowing systems during their first
168 and second farrowings, creating a 3 x 2 factorial design of farrowing system and
169 parity. Animals were allocated to whichever farrowing system was in rotation at their
170 time of housing.

171 *Data collection*

172 Data were collected from farm records for farrowings which occurred from November
173 2013 to January 2016. Sows which did not complete their first two lactations in full
174 were excluded from the database. Variables recorded for both parities were: animal
175 ID, farrowing system, farrowing date, litter size (live-born and stillborn), number and
176 cause of piglet mortality, weaning date and number of piglets at weaning. Piglet
177 mortalities were recorded as occurring either before or after litter processing, when
178 litters were first handled by staff at 4-16h post-partum. Cause of death was recorded
179 as either crushing, low viability, savaged or miscellaneous (including hypothermia,
180 congenital defects, or unknown cause) according to standard practice for the
181 mortality records on-farm.

182 *Statistical analysis of results*

183 Litter size and piglet mortality data were analysed in SAS 9.2 using the GLIMMIX
184 procedure. Models for first parity litter size (total born and live-born) included season
185 at farrowing (Spring = Mar, Apr, May; Summer = Jun, Jul, Aug; Autumn = Sep, Oct,
186 Nov; Winter = Dec, Jan, Feb), whilst models for second parity litter size included first
187 parity season at farrowing, first parity litter age at weaning and first parity farrowing
188 system. Due to a low incidence of mortality caused by savaging and by other
189 miscellaneous reasons, cause of mortality was grouped as either crushing or all other
190 causes (low viability, savaged and miscellaneous). All models regarding mortality
191 (including stillborn) included an underlying Poisson distribution. First parity mortality
192 models included total born litter size, the current farrowing system, the season at
193 farrowing and an interaction of the current farrowing system and season at farrowing.
194 Second parity base models also included the previous farrowing system and an
195 interaction between the current and previous farrowing system. For models

196 concerning post-processing and total mortalities, lactation length was also included in
197 the base model for both parities. Variables were excluded in a step-wise manner,
198 with all variables of $P < 0.10$ and interactions of $P < 0.05$ included in the final models.
199 Sow consistency between and within parities was analysed in SAS 9.2 using the
200 GENMOD procedure. Repeated measures models were created with sow ID as the
201 repeated subject. For between parity consistencies, the final second parity models
202 from the GLIMMIX procedure were used plus the corresponding first parity variable
203 as an additional independent variable (e.g. first parity pre-processing crushed to
204 predict second parity pre-processing crushed). For within parity consistencies, the
205 pre-processing variable was used to predict the post-processing variable (e.g. first
206 parity pre-processing crushed to predict first parity post-processing crushed) for both
207 the first and second parities independently.

208 **Results**

209 Data were collected from 753 sows across the three farrowing systems in parity one
210 and parity two, however system combination groups were not ideally balanced as
211 increasing numbers of 360s came into use on the farm (see Table 1).

212 TABLE 1 NEAR HERE.

213 Parity one mean total born litter size was 13.72 ± 0.10 , and did not differ across
214 seasons at farrowing ($P < 0.10$). Parity two mean total born litter size was $12.94 \pm$
215 0.11 , and also did not differ across seasons at farrowing ($P < 0.10$). However, there
216 was a tendency for parity one farrowing season to affect parity two total born litter
217 size ($P = 0.068$; spring= 13.01 ± 0.22 ; summer= 13.43 ± 0.23 ; autumn= 12.54 ± 0.24 ;
218 winter= 13.03 ± 0.21), being significantly higher for sows that previously farrowed in
219 the summer than the autumn ($P < 0.01$). Parity two total born litter size also tended to

220 increase with increasing parity one weaning age ($+0.056 \pm 0.031$ piglets per day; $P =$
221 0.075).

222 Total piglet mortality across all farrowing systems was significantly higher in the first
223 parity (16.85%; 14.84% of live-born piglets, 2.36% stillborn of total born piglets) than
224 the second parity (12.72%; 10.59% of live-born piglets, 2.38% stillborn of total born
225 piglets; Wilcoxon signed-rank test; $P < 0.0001$). Litter age and litter size at weaning
226 were similar for both parities (parity one: litter age= 24.85 ± 0.13 days, litter
227 size= 12.79 ± 0.03 piglets; parity two: litter age= 25.61 ± 0.12 days, litter size= $12.78 \pm$
228 0.03 piglets).

229 Significance levels of all variables from the final piglet mortality models are provided
230 in Table 2. Total born litter size, litter age at weaning, season and the interaction
231 between farrowing system and season were included in models only to account for
232 their possible effects on piglet mortality, and therefore will not be discussed further.

233 TABLE 2 NEAR HERE.

234 *Parity one*

235 *Effect of current farrowing system.* Total born litter size did not differ significantly
236 between farrowing systems (crate= 13.76 ± 0.18 ; 360s= 13.86 ± 0.16 ; pens= $13.43 \pm$
237 0.20). Figure 2 presents all mortality by category and current farrowing system for
238 parity one and two. There were significantly fewer stillbirths (number per litter) in the
239 pens than the 360s ($P < 0.01$) or the crates ($P < 0.001$). Pre-processing mortality
240 from crushing was significantly lower in the 360s than in the pens or the crates (both
241 $P < 0.01$), whilst no significant difference in pre-processing mortality from other
242 causes across farrowing systems was observed. This meant that pre-processing
243 mortality from all causes was significantly higher in the crates than the 360s ($P <$

244 0.0001), whilst mortality in the pens tended to be both lower than the crates ($P =$
245 0.066) and higher than the 360s ($P = 0.063$). Farrowing system had no significant
246 effect on post-processing mortality (crushing, other or all). Total piglet mortality from
247 crushing was lower in the 360s than the crates ($P < 0.05$) but not the pens; whilst
248 total piglet mortality from other causes did not differ significantly between farrowing
249 systems. As a result of these individual components, total live-born mortality and total
250 born mortality were significantly higher in the crates than both the pens (live-born: P
251 < 0.05 ; total born: $P < 0.01$) and the 360s (both $P < 0.01$).

252 FIGURE 2 NEAR HERE.

253 *Parity two*

254 *Effect of current farrowing system.* Total born litter size did not differ significantly
255 between farrowing systems (crate= 12.89 ± 0.29 ; 360s= 13.06 ± 0.15 ; pens= $12.94 \pm$
256 0.23). Figure 2 presents all mortality by category and current farrowing system for
257 parity two. There was no effect of the current farrowing system on the incidence of
258 stillborn piglets. Pre-processing mortality from crushing was significantly higher in the
259 crates than the pens ($P < 0.05$); whilst pre-processing mortality from other causes
260 was significantly higher in the crates than the pens or the 360s (both $P < 0.05$). Post-
261 processing mortality from crushing was significantly higher in the 360s than both the
262 crates and the pens (both $P < 0.05$), however, in combination, total crushing mortality
263 was significantly higher in the 360s than the pens only ($P < 0.05$). Post-processing
264 mortality from other causes, and therefore total mortality from other causes, was
265 significantly higher in the 360s than the pens (pre-other: $P < 0.0001$; total-other: $P <$
266 0.01). Post-processing mortality from all causes was significantly higher in the 360s
267 than both the crates and the pens (both $P < 0.001$), whilst total live-born mortality and

268 total born mortality were significantly higher in the 360s than the pens (live-born: $P =$
269 0.001 ; total born: $P < 0.01$), but not the crates.

270 *Effect of previous farrowing system.* Parity two total born and live-born litter sizes
271 were significantly affected by the parity one farrowing system, being higher if a sow
272 previously farrowed in the pens than both the 360s (total born: $P < 0.001$; live-born: P
273 < 0.01) and the crates (both $P < 0.01$; Table 3).

274 TABLE 3 NEAR HERE.

275 There was no effect of the previous farrowing system on the incidence of stillborn
276 piglets, pre-processing mortality from other causes or total pre-processing live-born
277 mortality. However, sows that previously farrowed in the pens had significantly lower
278 pre-processing crushing mortality (0.27 ± 0.04) than sows that previously farrowed in
279 the 360s (0.41 ± 0.04 ; $P < 0.05$), with previously penned sows also tending to be
280 lower than sows that previously farrowed in the crates (0.38 ± 0.05 ; $P = 0.055$).

281 Whilst post-processing crushing mortality was not significantly affected by the
282 previous farrowing system, post-processing mortality from other causes was
283 significantly higher if a sow had previously farrowed in the 360s (0.017 ± 1.48) than
284 the pens (0.008 ± 0.68 ; $P < 0.01$), but not the crates (0.012 ± 1.04). Moreover, post-
285 processing mortality from all causes was significantly higher for sows that previously
286 farrowed in the 360s (0.94 ± 0.08) than either the pens (0.60 ± 0.09 ; $P < 0.01$) or the
287 crates (0.61 ± 0.07 ; $P < 0.01$). There was no effect of the previous farrowing system
288 on total mortality from crushing or total mortality from other causes, however total
289 live-born mortality from all causes was significantly higher if a sow had previously
290 farrowed in the 360s (1.40 ± 0.10) than the pens (1.06 ± 0.11 ; $P < 0.05$), but not the
291 crates (1.17 ± 0.10).

292 *Effect of farrowing system interaction.* Total born litter size did not differ significantly
293 between farrowing system combinations (crate-crate= 12.27 ± 0.52 ; 360s-crate=
294 11.89 ± 0.54 ; pen-crate= 14.14 ± 0.42 ; crate-360s= 12.94 ± 0.25 ; 360s-360s= 12.72
295 ± 0.23 ; pen-360s= 13.48 ± 0.28 ; crate-pen= 12.51 ± 0.37 ; 360s-pen= 12.78 ± 0.28 ;
296 pen-pen= 12.77 ± 0.80). The interaction of the first and second farrowing systems
297 had no significant effect on the incidence of stillborn piglets, pre-processing mortality
298 (crushing, other or all) or post-processing mortality from other causes. However, an
299 interaction of the first and second farrowing systems did affect post-processing
300 mortality from crushing ($P < 0.01$) and therefore post-processing mortality from all
301 causes ($P < 0.001$; Figure 3). Consequently, total mortality from crushing ($P < 0.05$),
302 total mortality from other causes ($P < 0.01$) and total live-born mortality ($P < 0.01$)
303 were affected by the farrowing system interaction (Figure 3).

304 FIGURE 3 NEAR HERE.

305 *Effect of individual consistency of sow performance.* Parity two live-born litter size
306 and total born litter size increased with increasing parity one litter sizes (parity two
307 live-born piglets = $+0.156 \pm 0.042$ parity one live-born piglets, $P < 0.001$; parity two
308 total born piglets = $+0.155 \pm 0.043$ parity one total born piglets, $P < 0.001$). The
309 incidence of piglet mortality in parity two was not associated with the same category
310 of piglet mortality in parity one, except for the case of savaging (parity two savaging
311 frequency = $+0.281 \pm 0.139$ parity one savaging frequency, $P < 0.05$). Within the
312 same parity, first parity post-processing mortality (crushing, other and all) was
313 significantly associated with pre-processing mortality (post-crushing = $+0.083 \pm 0.039$
314 pre-crushing, $P < 0.05$; post-other = $+0.235 \pm 0.067$ pre-other, $P < 0.001$; post-all =
315 $+0.126 \pm 0.035$ pre-all, $P < 0.001$). However, in the second parity, there was no
316 association between pre- and post-processing mortality.

317 **Discussion**

318 To our knowledge, this is the first research paper to report a significant effect of an
319 interaction between the current and previous farrowing systems experienced by the
320 sow on current piglet mortality. Specifically, in the second parity, post-processing
321 mortality in the crates was significantly decreased if a sow previously farrowed in a
322 crate, whereas post-processing mortality in the 360s was significantly increased if a
323 sow previously farrowed in a crate. These findings support our primary hypothesis
324 that inter-parity farrowing system consistency is important for sow performance, in
325 some cases more so than the specific farrowing system used. Previously crated
326 sows may have increased piglet mortality in less confined systems as they have had
327 no previous experience of learning to avoid the increased risk of piglet crushing
328 associated with reduced confinement. Moreover, sows that previously farrowed in the
329 pens or 360s have no experience of prolonged confinement, which is associated with
330 increased physiological stress (Jarvis *et al.*, 2006). Sow maternal behaviour is
331 considered an important factor for piglet survival (Wechsler and Hegglin, 1997;
332 Andersen *et al.*, 2005), and its performance is highly dependent on the physical
333 constraints of the immediate farrowing environment. Earlier studies have also shown
334 sow farrowing behaviour to be affected by the preceding environment of the sow,
335 including during gestation (Boyle *et al.*, 2002), farrowing (Thodberg *et al.*, 2002a and
336 2002b) and rearing (Chidgey *et al.*, 2016), indicating that sow maternal behaviour
337 develops according to previous environmental experiences. Repeated housing in the
338 same farrowing system would therefore enable sows to adapt and perfect their
339 maternal behaviours for that specific farrowing system, resulting in optimised
340 reproductive success. However, in the current study, this reasoning was not entirely
341 supported, as post-processing mortality in the 360s was lowest if a sow previously

342 farrowed in a pen. Therefore, prior experience of farrowing without confinement may
343 be important for reducing piglet mortality across systems with periods of non-
344 confinement. The condition of repeated housing in the 360s may not have reduced
345 piglet mortality as data collection occurred whilst this system was being introduced
346 on-farm, meaning that management routines fluctuated across the study period as
347 stockpersons developed the most appropriate management.

348 Second parity post-processing piglet mortality in the pens was also lowest for sows
349 that had previously farrowed in the pens. However, this result was not significant,
350 which may be attributable to the small sample size of the pen-pen group (15 sows)
351 and hence the larger standard error around the numerically lower mean value.
352 Alternatively, differences in mortality caused by the previous farrowing system may
353 have been less pronounced due to the pen system being a distinctly different
354 farrowing system. Consequently, second parity sows which previously farrowed in a
355 crate or 360s may have easily discriminated the pen as a different environment and
356 not used their prior experience to adapt farrowing behaviour, opting instead to relearn
357 how to optimise behaviour for the new environment. This reasoning would also
358 explain why post-processing mortality was particularly high for sows that
359 interchanged between the crate and 360s systems. When these sows were housed
360 for farrowing in their second parity, they would have been less able to discriminate a
361 change of environment and therefore relied upon previous farrowing experience. In
362 later lactation, this would be problematic as the behaviours adapted for prolonged
363 confinement or reduced confinement may not be optimal for piglet survival in the
364 contrasting environment (crate-360s or 360s-crate). Our suggestion would be that if
365 farms do require to change sows between farrowing systems, they should ensure the

366 farrowing systems are sufficiently different for sows to easily discriminate between
367 them.

368 The majority of piglet mortality occurs during the first 24 hours of life, with a
369 predominant cause being accidental crushing by the sow (Marchant *et al.*, 2000). In
370 the current study, pre-processing crushing mortality was significantly lower in the
371 360s than the crates or pens in first parity gilts. Earlier studies have shown gilts to
372 exhibit increased sensitivity to the farrowing environment (Jarvis *et al.*, 2001;
373 Thodberg *et al.*, 2002a), whilst pre-partum confinement without nesting material in
374 crates causes physiological stress (Jarvis *et al.*, 1997). Conversely, gilts in both the
375 360s and pens may have had sufficient space and material to perform pre-partum
376 nesting, leading to increased sow responsiveness towards the piglets (Cronin and
377 van Amerongen, 1991; Thodberg *et al.*, 2002b). Therefore, the lower mortality
378 observed in the 360s may have resulted from the combined benefits of both
379 facilitated nest-building for the dam and increased protection from crushing for the
380 neonates. However, pre-processing crushing mortality in the second parity was
381 unaffected by the current farrowing system, but lower if a sow had previously
382 farrowed in a pen than a crate, further suggesting that early periparturient behaviour
383 adapted to the farrowing system experienced during the first farrowing. The prior
384 experience of unconstrained nest-building and/or farrowing in previously penned
385 sows may have resulted in improved maternal behaviour in the second parity, whilst
386 behaviour later developed to reflect the previous and current environments as sows
387 continually try to adapt their behaviours to the farrowing system in use.

388 Piglet mortality was lower in parity two across all farrowing systems, suggesting
389 improvements in maternal behaviour with prior experience across all treatment
390 combinations. However, the reduction in piglet mortality was the least in the 360s,

391 specifically due to higher post-processing mortality in this system. When the 360s
392 crates are opened at ten days post-partum, sows are required to adapt their
393 behaviour mid-lactation due to the abrupt environmental change from confinement to
394 non-confinement. A separate study conducted by the authors on the same farm
395 found significantly increased piglet mortality during the period immediately after
396 temporary confinement crates are opened (King *et al.*, submitted), therefore
397 temporary confinement systems may not have improved piglet survival over free
398 farrowing systems, as found in the current study. The effect of crate opening in
399 increasing piglet mortality may not have been observed in the first parity where post-
400 processing mortality was equally high across all systems, as all gilts were learning
401 how to cope with lactation irrespective of the farrowing system. Piglet mortality in the
402 second parity may also have been higher in the 360s due to the relatively small area
403 available to the larger sow after crate opening in comparison to the pen, as piglet
404 mortality has been found to increase in loose lactation pens smaller than 5.0m²
405 (Weber *et al.*, 2009). The results from the second parity sows in the current study are
406 consistent with this, with total piglet mortality higher than crates in the 360s (4.0m²)
407 but not pens (total 7.86m²).

408 Whilst the current study relied on stockperson records regarding the incidence and
409 cause of piglet mortality, data were collected on a single farm by the same staff.
410 Therefore, any inaccuracies regarding piglet mortality incidence and diagnosis would
411 have been similar across farrowing systems and parities, and consequently should
412 not have confounded the final results. However, stockperson biases regarding the
413 different farrowing systems might subconsciously affect the reported cause of piglet
414 mortality, i.e. stockpersons may attribute more deaths to crushing in free farrowing
415 systems as they believe crushing to be more prevalent in these systems. Whilst

416 stockpersons in the current study were unavoidably aware of which farrowing system
417 a sow was currently housed in, stockpersons were predominantly unaware of which
418 system a sow had previously farrowed in.

419 The farrowing system used can also have longer term effects on sow performance,
420 as sows which farrowed in the pens during their first parity had a significantly larger
421 total born and live-born litter size in their second parity. To our knowledge, only one
422 other study has investigated the effect of the lactation environment on subsequent
423 litter size, and found no difference between standard and temporary confinement
424 crates (Chidgey *et al.*, 2015), which was also found to be the case in the current
425 study. A lower weight loss during lactation results in improved subsequent
426 reproductive performance (Thaker and Bilkei, 2005), which may have occurred in
427 penned gilts. For example, voluntary feed intake of sows is sometimes higher in free
428 farrowing than crated systems (Cronin *et al.*, 2000), whilst sows housed in non-
429 restrictive systems exhibit more control over nursing behaviour (Arey and Sancha,
430 1996; Thodberg *et al.*, 2002b), and therefore may begin weaning the litter and
431 reducing metabolic demand before on-farm weaning occurs. In the current study,
432 increasing first parity lactation length also tended to increase second parity litter size,
433 which has been found previously and postulated to result from an improved
434 metabolic status at service (Hidalgo *et al.* 2014).

435 Sows are believed to show individual consistency in reproductive performance. Total
436 born and live-born litter sizes are known to be individually consistent across parities,
437 as found in the current study, meaning this trait is already used within commercial
438 breeding indices (Su *et al.*, 2007). However, piglet survival to five days post-partum
439 has also become a selected indicator of reproductive performance (Su *et al.*, 2007).
440 The current study found no sow consistency in piglet mortality across parities, whilst

441 piglet mortality did show individual consistency between pre- and post-processing
442 mortality in the first but not second parity. Sow behaviour during the first parity will be
443 highly dependent on the immediate farrowing environment, but also the individual
444 reaction pattern of the sow (Thodberg *et al.*, 2002a), and therefore it would be
445 expected for piglet mortality to show individual consistency throughout the first
446 farrowing and lactation. In contrast, pre-processing mortality in the second parity is
447 more affected by the previous than the current farrowing system; whilst individual
448 differences in behavioural adaption of sows to the second parity system may mean
449 pre- and post-processing mortality are not consistent. To our knowledge, no previous
450 studies investigating the consistency of sow performance did so across different
451 farrowing systems; therefore the observed consistencies in previous studies may
452 actually reflect the sows' individual ability to adapt to the particular farrowing system
453 used. This highlights the need for farms using multiple farrowing systems to ensure
454 sows return to the same system over repeated farrowings to express individual
455 consistency in reproductive performance.

456 In conclusion, housing second parity sows in the same farrowing system as their
457 previous farrowing may reduce piglet mortality. Sows which farrowed in the pens
458 during their first parity had additional production benefits of a significantly larger litter
459 size and lower pre-processing crushing mortality in their second parity. It is
460 recommended that commercial farms rehouse sows in the same farrowing system to
461 maximise consistency in sow performance. However, if sows must be changed
462 between farrowing system, the systems should be sufficiently different to enable
463 sows to discriminate between, which may reduce the impact on piglet mortality.

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466 involved for their commitment to using higher welfare farrowing systems, permitting
467 the use of their existing farm records and facilitating the research. We would also like
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469 **Declaration of interest**

470 No conflict of interest to declare.

471 **Ethics statement**

472 The project received ethical approval from Newcastle University.

473 **Software and data repository resources**

474 Data not available in an official repository.

475 **References**

- 476 Andersen IL, Berg S and Bøe KE 2005. Crushing of piglets by the mother sow (*Sus scrofa*) -
477 Purely accidental or a poor mother? *Applied Animal Behaviour Science* 93, 229–243.
- 478 Arey DS 1997. Behavioural observations of peri-parturient sows and the development of
479 alternative farrowing accommodation: a review. *Animal Welfare* 6, 217-229.
- 480 Arey DS and Sancha ES 1996. Behaviour and productivity of sows and piglets in a family
481 system and in farrowing crates. *Applied Animal Behaviour Science* 50, 135–145.
- 482 Boyle LA, Leonard FC, Lynch PB and Brophy P 2002. Effect of gestation housing on
483 behaviour and skin lesions of sows in farrowing crates. *Applied Animal Behaviour*
484 *Science* 76, 119-134.
- 485 Chidgey KL, Morel PCH, Stafford KJ and Barugh IW 2015. Sow and piglet productivity and
486 sow reproductive performance in farrowing pens with temporary crating or farrowing
487 crates on a commercial New Zealand pig farm. *Livestock Science* 173, 87-94.
- 488 Chidgey KL, Morel PCH, Stafford KJ and Barugh IW 2016. The performance and behaviour

489 of gilts and their piglets is influenced by whether they were born and reared in farrowing
490 crates or farrowing pens. *Livestock Science* 193, 51-57.

491 Cronin GM, Lefébure B and McClintock S 2000. A comparison of piglet production and
492 survival in the Werribee Farrowing Pen and conventional farrowing crates at a
493 commercial farm. *Australian Journal of Experimental Agriculture* 40, 17-23.

494 Cronin GM and van Amerongen G 1991. The effects of modifying the farrowing environment
495 on sow behaviour and survival and growth of piglets. *Applied Animal Behaviour Science*
496 30, 287-298.

497 Edwards SA, Brett M, Ison S, Jack M, Seddon YM and Baxter EM 2012. Design principles
498 and practical evaluation of the PigSAFE free farrowing pen. In *Proceedings of the 4th*
499 *European Symposium on Porcine Health Management (ESPHM)*, 25-27 April 2012,
500 Bruges, Belgium, pp113.

501 Farm Animal Welfare Committee 2015. *Opinion on free farrowing systems*. Department for
502 Environment, Food and Rural Affairs, Westminster, London, UK.

503 Farm Animal Welfare Council 1996. *Report on the Welfare of Pigs Kept Outdoors*.
504 Department for Environment, Food and Rural Affairs, Westminster, London, UK.

505 Hales J, Moustsen VA, Nielsen MBF and Hansen CF 2014. Higher preweaning mortality in
506 free farrowing pens compared with farrowing crates in three commercial pig farms.
507 *Animal* 8, 113–120.

508 Hales J, Moustsen VA, Nielsen MBF and Hansen CF 2015. Temporary confinement of loose-
509 housed hyperprolific sows reduces piglet mortality. *Journal of Animal Science* 93, 4079-
510 4088.

511 Hidalgo DM, Friendship RM, Greiner L, Manjarin R, Amezcua MR, Dominguez JC and
512 Kirkwood RN 2014. Influence of lactation length and gonadotrophins administered at
513 weaning on fertility of primiparous sows. *Animal Reproduction Science* 149, 245–248.

- 514 Jarvis S, D'Eath RB, Robson SK and Lawrence AB 2006. The effect of confinement during
515 lactation on the hypothalamic-pituitary-adrenal axis and behaviour of primiparous sows.
516 *Physiology & Behavior* 87, 345–352.
- 517 Jarvis S, Lawrence AB, McLean KA, Deans LA, Chirnside J and Calvert SK 1997. The effect
518 of environment on behavioural activity, ACTH, (β -endorphin and cortisol in pre-farrowing
519 gilts. *Animal Science* 65, 465–472.
- 520 Jarvis S, Van der Vegt BJ, Lawrence AB, McLean KA, Deans LA, Chirnside J and Calvert SK
521 2001. The effect of parity and environmental restriction on behavioural and physiological
522 responses of pre-parturient pigs. *Applied Animal Behaviour Science* 71, 203–216.
- 523 KilBride AL, Mendl M, Statham P, Held S, Harris M, Cooper S and Green LE 2012. A cohort
524 study of preweaning piglet mortality and farrowing accommodation on 112 commercial
525 pig farms in England. *Preventive Veterinary Medicine* 104, 281–291.
- 526 King RL, Baxter EM, Matheson SM and Edwards SA *submitted*. Temporary crate opening
527 procedure affects immediate post-opening piglet mortality and sow behaviour.
528 Submitted to *Animal*.
- 529 Lassen BJ, Sandøe P and Forkman B 2006. Happy pigs are dirty! – conflicting perspectives
530 on animal welfare. *Livestock Science* 103, 221–230.
- 531 Marchant JN, Rudd AR, Mendl MT, Broom DM, Meredith MJ, Corning S and Simmins PH
532 2000. Timing and causes of piglet mortality in alternative and conventional farrowing
533 systems. *Veterinary Record* 147, 209-214.
- 534 Royal Society for the Prevention of Cruelty to Animals 2016. RSPCA welfare standards for
535 pigs, Horsham, UK.
- 536 Su G, Lund MS and Sorensen D 2007. Selection for litter size at day five to improve litter size
537 at weaning and piglet survival rate. *Journal of Animal Science* 85, 1385-1392.
- 538 Thaker MYC and Bilkei G 2005. Lactation weight loss influences subsequent reproductive

539 performance of sows. *Animal Reproduction Science* 88, 309–318.

540 Thodberg K, Jensen KH and Herskin MS 2002a. Nest building and farrowing in sows:
541 Relation to the reaction pattern during stress, farrowing environment and experience.
542 *Applied Animal Behaviour Science* 77, 21–42.

543 Thodberg K, Jensen KH and Herskin MS 2002b. Nursing behaviour, postpartum activity and
544 reactivity in sows: Effects of farrowing environment, previous experience and
545 temperament. *Applied Animal Behaviour Science* 77, 53–76.

546 Weber R, Keil NM, Fehr M and Horat R 2009. Factors affecting piglet mortality in loose
547 farrowing systems on commercial farms. *Livestock Science* 124, 216–222.

548 Wechsler B and Hegglin D 1997. Individual differences in the behaviour of sows at the nest-
549 site and the crushing of piglets. *Applied Animal Behaviour Science* 51, 39–49.

550 Yun J, Swan K, Vienola K, Farmer C, Oliviero C, Peltoniemi O and Valros A 2013. Nest-
551 building in sows: Effects of farrowing housing on hormonal modulation of maternal
552 characteristics. *Applied Animal Behaviour Science* 148, 77–84.

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561 **Table 1.** *Distribution of sows across farrowing systems in first parity (columns) and second*
 562 *parity (rows).*

Second parity system	First parity system			Total
	Crate	360s	Pen	
Crate	37	33	55	125
360s	143	172	116	431
Pen	67	115	15	197
Total	247	320	186	753

563

564 **Table 2.** Significance level of independent variables for piglet mortality in the first and second parity. Mortality is classified by cause
 565 and whether it occurred prior to (Pre-) or subsequent to (Post-) piglet processing at 4-16 hours after birth. The direction of
 566 association for continuous variables is positive in all cases.

Mortality type	Parity one					Parity two						
	Total born	System (current)	Season	Syst* Seas ¹	Wean age	Total born	System (current)	System (previous)	System (interaction)	Season	Syst* Seas ¹	Wean age
Stillborn	****	**			-	****						
Live-born												
Crushed												
Pre-	***	**		*	-	****		*			**	-
Post-	*		****		****	*	**		**	*		**
Total	****			*	****	****	*		*		**	**
Other causes												
Pre-	***		**		-	**						-
Post-	****			**			****	**			*	****
Total	****		**	*		*	**		**	****	***	**
All live-born												
Pre-	****	***			-	****						-
Post-	****		**	*	****	*	****	***	****	****	***	****
Total	****	*	*	**	****	****	**		**	**	***	****

567 * (P<0.05), ** (P<0.01), *** (P<0.001), **** (P<0.0001), - (not included in base model).

568 ¹ Current system and current season interaction.

569 **Table 3.** *Table of least square means (\pm s.e.) for second parity sow total born and*
 570 *live-born litter size by first parity farrowing system.*

Second parity litter size	First parity farrowing system			P value
	Crate	360s	Pen	
Total born	12.73 \pm 0.19 ^a	12.65 \pm 0.17 ^a	13.62 \pm 0.22 ^b	< 0.001
Live-born	12.39 \pm 0.19 ^a	12.46 \pm 0.16 ^a	13.24 \pm 0.21 ^b	< 0.01

571 ^{a,b} Values within a row with different superscripts differ significantly as indicated.

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587 **Figure captions**

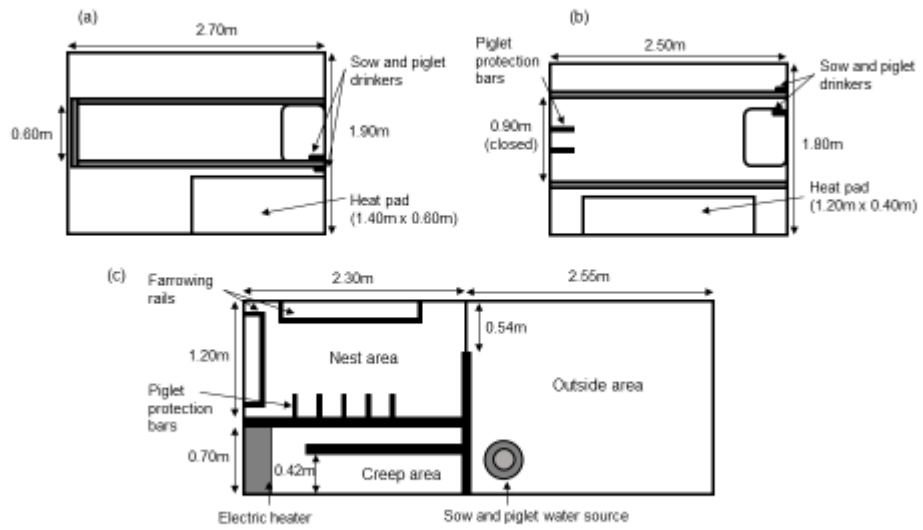
588 **Figure 1.** Sow farrowing system pen layouts to scale for (a) the standard farrowing
589 crate, (b) the 360° Freedom Farrower and (c) the straw-based pen with outside run.

590 **Figure 2.** Least square means (\pm s.e.) for total piglet mortality by type and current
591 farrowing system for parities one (left) and two (right). Piglet mortality type is
592 classified by both cause (stillborn, crushing or other) and whether it occurred pre- or
593 post- piglet processing at 4-16 hours after birth. Significantly differing frequencies (P
594 < 0.05) between farrowing systems are indicated with differing letters for each piglet
595 mortality type (alongside each system) and total piglet mortality (above each system).

596 **Figure 3.** Least square means (\pm s.e.) of post-processing and total (pre- plus post-
597 processing) second parity live-born piglet mortality from crushing (upper) and all
598 causes (crushing plus other; lower) by parity one and parity two farrowing systems.
599 Parity one system effects within each parity two farrowing system are indicated, with
600 significant differences between Crate-360s and Crate-Pen indicated on the latter
601 system and between 360s-Pen indicated between these systems ($*(P < 0.05)$, $** (P <$
602 $0.01)$, $*** (P < 0.001)$).

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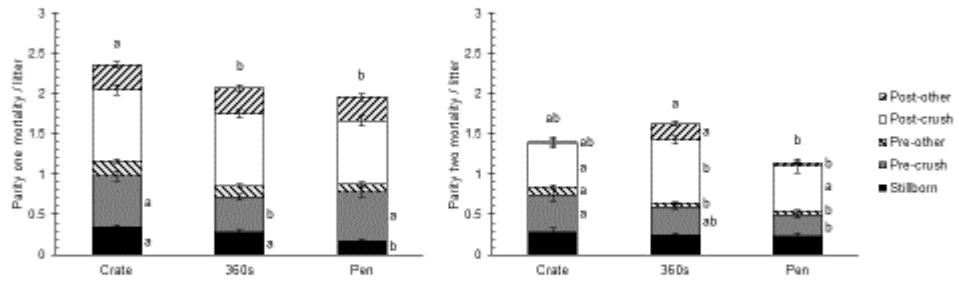
604 Fig 1.



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606 Fig 2

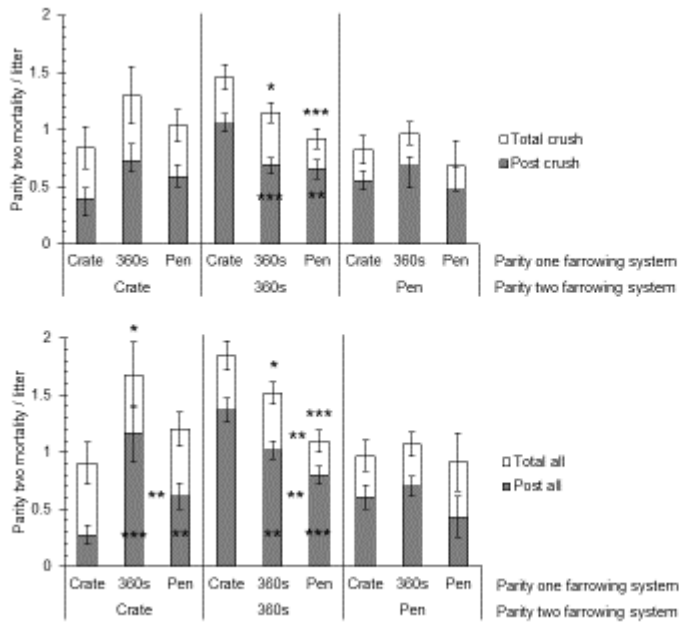
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609 Fig 3

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612 *Animal journal*

613 *Supplementary file*

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615 **Consistency is key: interactions of current and previous farrowing system on litter size**
616 **and piglet mortality**

617 R.L. King¹, E.M. Baxter², S.M. Matheson¹ and S.A. Edwards¹

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620 **Supplementary Methods**

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623 *Figure S1. Sow temporary confinement 360s illustrating the crates in both the open*
624 *(left) and closed (right) position (image courtesy of EM Baxter).*

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629 *Figure S2.* Indoor nest area of straw-based sow farrowing pen, with creep located to
630 the right (image courtesy of RL King).

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635 *Figure S3. Outdoor dunging area of straw-based sow farrowing pen, including*
636 *drinking water source (raised circle; image courtesy of RL King).*