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1 **Nurse sow strategies in the domestic pig: II. Consequences for piglet growth,**
2 **suckling behaviour and sow nursing behaviour**

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13
14 Short title: Nurse sow strategies and piglet performance

15
16 **Abstract**

17 Nurse sow strategies are used to manage large litters on commercial pig farms.

18 However, new-born piglets transferred to nurse sows in late lactation might be
19 compromised in terms of growth and survival. We investigated the effects of two

20 nurse sow strategies on piglet growth, suckling behaviour and sow nursing

21 behaviour. One day post-farrowing, the four heaviest piglets from large litters were

22 transferred to a nurse sow either 21 (1STEP21, n=9 litters) or 7 (2STEP7, n=10

23 litters) days into lactation. The remainder of the litter remained with their mother and

24 was either kept intact (Remain Intact (RI), n=10 litters), or had some piglets cross-

25 fostered to equalise birthweights (Remain Equalised (RE), n=9 litters). The 7 day old

26 piglets from 2STEP7 were transferred onto a sow 21 days into lactation (2STEP21,
27 n=10 litters The growth of new-born piglets on 1STEP21 and 2STEP7 nurse sows
28 was initially lower than in RI litters ($F_{3,33.8}=4.61$, $P<0.01$), but weaning weights did not
29 significantly differ ($F_{4,32.7}=0.78$, $P>0.5$). After the first week of lactation, the weights
30 and growth rates did not differ between treatments. Fighting behaviour during
31 nursing bouts decreased over time. The frequency of fights was higher in 1STEP21
32 and 2STEP21 litters compared to RI litters ($t_{122}=3.06$ and $t_{123}=3.00$, respectively,
33 $P<0.05$). 2STEP21 litters had shorter nursing bouts than RI and 1STEP21 litters (t_{107}
34 $=-2.81$ and $t_{81.7}=2.8$, respectively, $P<0.05$), which were more frequently terminated
35 by 2STEP21 than RI sows ($t_{595}=2.93$, $P<0.05$). Transferring heaviest piglets from RI
36 and RE litters to nurse sows reduced the percentage of teat changes during nursing
37 bouts (RI: $F_{1,275}=16.61$, RE: $F_{1,308}=43.59$; $P<0.001$). In conclusion, nurse sow
38 strategies do not appear to compromise piglet growth. However, new-born piglets
39 transferred onto sows in late lactation experienced more competition at the udder
40 suggesting that the sows' stage of lactation is of importance to how achievable nurse
41 sow strategies are. Thus, the two-step nurse sow strategy is likely the best option (in
42 relation to growth and suckling behaviour) as it minimises the difference between
43 piglet age and sow stage of lactation.

44

45 **Keywords:** large litters, pig, behaviour, performance, welfare

46

47 **Implications**

48 This study suggests that when the heaviest piglets from a large litter are transferred
49 to a nurse sow either 7 or 21 days into lactation, there is minimal impairment in
50 growth, compared to piglets reared by their mother. However, competition at the

51 udder increased with the nurse sow's stage of lactation, which may impair piglets'
52 welfare. Hence, matching piglet age with the nurse sow's stage of lactation is
53 important for optimising nurse sow strategies. Further studies should investigate the
54 effect of transferred piglets' weight on the success of nurse sow strategies, and use
55 larger sample size to investigate survival.

56

57 **Introduction**

58 Genetic selection for large litters has resulted in more piglets being born alive (AHDB
59 Pork, 2016), which represents a challenge for both piglets and sows (Rutherford *et*
60 *al.*, 2013). If the number of piglets born alive exceeds the number of functional teats,
61 one consequence is a high level of fighting at the udder for access to a functional
62 teat, which can hinder the uptake of adequate colostrum and milk (Rutherford *et al.*,
63 2013). Selection for large litters in commercial hybrid sows has not been
64 accompanied by a concomitant improvement in milk quality/composition (Hurley,
65 2015) or yield (Quesnel, 2011). Therefore, there is likely more competition between
66 piglets during nursing in hyper-prolific hybrid sows, which potentially compromises
67 piglets' pre-weaning growth and places piglets failing to win this competition at
68 greater risk of dying in early lactation (Rutherford *et al.*, 2013). Therefore,
69 management strategies are needed to optimise survival and growth of all the piglets
70 born into large litters (for a review see Baxter *et al.*, 2013). As behaviour of both sow
71 and piglets is important to optimise survival and growth of piglets, notably during
72 nursing bouts, evaluation of these strategies should include behavioural measures.
73 Cross-fostering is a commonly used management procedure which equalises litters
74 of sows that farrowed in the same period of time by fostering extra piglets from large
75 litters (i.e. over 14 piglets born alive) to smaller litters (i.e. up to 12 piglets born alive),

76 where functional teats are available. The timing of fostering is important to optimise
77 its success, as fostering too early may compromise colostrum intake whereas
78 fostering too late may reduce acceptance by the foster sow and cause distress (i.e.
79 negative state due to failure to cope with intense stressor; Ward et al., 2008) to the
80 piglets, which have already bonded with their mother and established a teat order
81 (Baxter *et al.*, 2013). A common problem of cross-fostering is that the foster sow may
82 be able to discriminate between her own offspring and fostered piglets, and might
83 reject or show aggressiveness towards the latter (Reese and Straw, 2006).

84 Furthermore, in hyper-prolific herds, the majority of sows are likely to farrow large
85 litters thereby limiting opportunities for cross-fostering.

86 Using nurse sows to raise whole litters of super-numerous piglets is an increasingly
87 popular management strategy to overcome these challenges. For instance, in
88 Denmark, where the number of piglets weaned per sow is the highest in EU (AHDB
89 Pork, 2017), on average 15% (up to 45%) of sows are used as nurse sows after
90 weaning their own litter (Pedersen, 2016). There are two types of nurse sow
91 strategy, known as “one-step” and “two-step” (Baxter *et al.*, 2013). “One-step”
92 involves weaning a sows own piglets at 21 days of lactation, and then transferring
93 new-born piglets (post-colostrum intake) to that sow to rear until weaning. “Two-step”
94 also involves weaning piglets at 21 days, but instead of receiving new-born piglets,
95 the nurse sow receives 7 day old piglets to rear to weaning. The sow from which the
96 7 day old piglets were removed then receives surplus new-born piglets. The two-step
97 strategy is the one most commonly used on Danish farms (up to 85% of survey
98 respondents; Pedersen, 2016). Normal farm practices imply transferring to the nurse
99 sow an equal or lower number of piglets than she has reared. Also, success of the
100 strategies is likely to be optimal when fostering heavier piglets, which should cope

101 better with fostering (Heim *et al.*, 2012) as they have a better chance of survival and
102 can compete more successfully for a teat than lighter piglets (e.g. Baxter *et al.*, 2008;
103 Milligan *et al.*, 2001; Tuchscherer *et al.*, 2000).

104 Although they have as yet received little scientific attention, nurse sow strategies are
105 theoretically a promising method of rearing surplus piglets as some of the challenges
106 associated with traditional cross-fostering are removed. For example, the absence of
107 the sows' own offspring should reduce aggression arising from competition for a teat
108 and possible aggression of the sow towards fostered piglets. However, one concern
109 is the nurse sow's capacity to produce a sufficient quantity and quality of milk during
110 the extended lactation period. Indeed, there is a decrease in fat, protein and energy
111 content between day 2 and 21 of lactation (Hurley, 2015), which emphasises the
112 importance of investigating the effect of feeding neonatal piglets with milk from a sow
113 21 days into lactation. Thorup (2015) showed that piglets transferred to a nurse sow
114 in early lactation had a higher growth and survival rate than piglets transferred to a
115 nurse sow in late lactation. The implications of nurse sow strategies on piglets'
116 behaviour and welfare have not been investigated. The two-step strategy could have
117 more negative implications for piglets' welfare than the one-step strategy, as 4-7 day
118 old piglets have bonded with their mother and hence could experience distress when
119 separated from her (Newberry and Swanson, 2008). The production of high-pitched
120 vocalisations (i.e. screams) by the isolated piglet is a measure of acute separation-
121 induced distress (Weary and Fraser, 1997).

122

123 The present study investigated different nurse sow strategies. The main hypothesis
124 was that both "one-step" and "two-step" would be effective rearing strategies, i.e. the
125 welfare of transferred piglets (assessed using growth rate, survival and aspects of

126 piglet and sow behaviour) would not be different to those reared by their mother.
127 Since the commercial approach is to select heavier piglets for fostering, it was also
128 expected that piglets transferred to a nurse sow in early lactation would have similar
129 growth rates to piglets remaining with their birth mother and a higher growth rate
130 than piglets transferred to a nurse sow in late lactation. It was predicted that there
131 would be more aggression during nursing bouts in litters of transferred piglets than in
132 litters of piglets remaining with their birth mother. Finally it was predicted that 7 day
133 old piglets would experience more distress after transfer to a nurse sow than new-
134 born piglets.

135

136 **Material and Methods**

137 *Animals and experimental design*

138 This experiment was conducted on a commercial farm in Co. Cork, Ireland, and
139 involved a total of 47 sows and 596 piglets. This farm was selected for the study as
140 the farm staff had experience with nurse sow strategies and the weekly farrowings
141 allowed evaluation of both 1-step and 2-step nurse sow strategies. Data were
142 collected on the rearing sows (nurse and mother) to evaluate the effect of the
143 strategies on selected measures of welfare (Schmitt et al., under review). Sample
144 size was based on power calculation (SAS 9.4) using weaning weights from the
145 available literature (Thorup, 2015). With a sample size of 10 litters per treatment, the
146 power was estimated at 0.8. The genetic background of the piglets was ((Large
147 White x Landrace) x PIC337).

148 Piglets were born in conventional farrowing pens (2.7 x 1.7 m; sow crate: 2.25 x 0.64
149 m) equipped with a heated mat on each side of the pen (1.55 x 0.37 m; maintained
150 at 30°C). No straw or bedding was provided to the sows or piglets. Farrowing rooms

151 were ventilated through fan chimneys (negative pressure principle) and temperature
152 was maintained at 23°C until the last farrowing and then lowered to 20°C until
153 weaning. Each week, a sow having a large litter (15 or more piglets born alive) was
154 selected as a “donor” for the experiment. Litter size was the only selection criterion,
155 although lame sows or sows with a poor body condition were not selected. Only one
156 primiparous sow (gilt) was recruited in the trial. The 4 (± 1.0) heaviest (1.8 ± 0.04 kg)
157 and most vigorous (highest scores in the “bucket test” of Muns *et al.*, 2014) piglets
158 from this sow were selected (balanced for sex) and transferred at 1 day old to a
159 nurse sow. For the bucket test, piglets were isolated for 30 s in a round enclosure
160 and scored for locomotion (0 = does not move to 2 = walks along the bucket limits
161 twice) and head movements (0 = no movements, 1 = circular head movements or
162 searching behaviour). The “one-step” and “two-step” strategies were applied
163 alternatively every week, thus 1 day old piglets could be transferred to a nurse sow
164 21 days into lactation (“one-step”, 1STEP21, n=10) or 7 days into lactation (“two-
165 step”, 2STEP7, n=9). Seven day old piglets from 2STEP7 were transferred to a
166 nurse sow 21 days into lactation (“two-step”, 2STEP21, n=9). The 21 day old piglets
167 from 1STEP21 and 2STEP21 were weaned and not considered further in the study.
168 Details of the timing of the transfers and schematic representation of the two
169 strategies can be found in Schmitt *et al.*, (accepted). The remainder of the donor
170 sows litter would either Remain Intact (RI, n=10 litters) or have approximately 2
171 (± 1.1) piglets removed or added as appropriate to equalise litter weight (Remain
172 Equalised, RE, n=9 litters). Piglets added to RE sows were selected by matching the
173 average weight in the litter, and thus to reduce weight variability in those litters. In
174 1STEP21 and 2STEP7 litters, piglets from non-experimental sows also born within
175 the same 24-h period were added to the recruited piglets to make up the remainder

176 of the litter. Thus, after the nurse sow strategies were applied, all experimental litters
177 had about 12 (± 0.1) piglets. Nurse sows were recruited according to their maternal
178 ability (i.e. 12 piglets alive and no piglet crushed at the time of selection) and body
179 condition (visual appraisal by farm staff based on a 1–5 scale of increasing condition;
180 Muirhead and Alexander, 1997). For ethical reasons, piglets in any of the
181 experimental treatments not thriving during lactation (i.e. failing to gain weight) were
182 removed from the experiment, transferred to a non-experimental sow and recorded
183 as “rearing failure”.

184 All post-weaning accommodation were fully slatted (plastic coated) and contained a
185 collective feeder, a nipple water dispenser and at least two ropes. Pigs were weaned
186 at approximately 30.8 (± 0.04) days of age and were moved to first stage weaner
187 accommodation (enclosure: 3 x 2.35 m; 33 pigs; maintained at 27°C). Pigs were
188 transferred to the second stage weaner accommodation at approximately 51.9
189 (± 0.04) days of age (enclosure: 6 x 2.3 m; 40 pigs; maintained at 23°C). However,
190 pigs were moved according to the visual appraisal of their body condition by the farm
191 staff, implying some age differences between pigs at these time points.

192

193 *Nutrition*

194 All diets were formulated and milled on the farm. Details of the sow nutrition can be
195 found in Schmitt *et al.* (in preparation). Briefly, sows were fed increasing amounts of
196 lactation diet (35 MJ/day at farrowing to 112 MJ/day at weaning). Piglets were given
197 a mix of water and electrolytes 24 h post-farrowing. From 16 days of age they
198 received creep feed once a day in a plastic trough attached to the slats. Three days
199 before weaning, piglets received a weaner diet containing 18.00% protein, 14.80
200 MJ/kg DE and 10.20 MJ/kg NE; which was also given in the first stage weaner

201 accommodation. When pigs were moved to the second stage weaner
202 accommodation, they received a diet containing 18.28% protein, 14.35 MJ/kg DE
203 and 10.28 MJ/kg NE. In both first and second stage weaner accommodation, feed
204 was provided ad libitum (probe feeding system; Spotmix, Schauer) in a long trough
205 system (2 m long; allowing approximately 15 pigs to eat simultaneously).

206

207 *Measurements*

208 *Survival and transfers.* The death of experimental piglets was recorded from D0 until
209 weaning. Piglets which were removed from the experiment because they failed to
210 gain weight were also recorded and analysed separately.

211

212 *Weight.* Piglets were weighed individually on D0, D1, and every Friday until weaning
213 (D3, D10, D17, and D24). They were also weighed at weaning (W), 7 days after
214 weaning (W7) and at transfer to the second stage weaner accommodation (S2).
215 Average daily gain (ADG) was calculated between each of these time points.

216

217 *Behaviour following transfer to the nurse sow.* Only piglets transferred to a nurse
218 sow were observed. Piglets were identified with sequential numbers marked on their
219 back, renewed between observation days. Direct observations were carried out by a
220 single observer, not blinded to treatments.

221 Piglets were transferred to the nurse sow as a group and placed on the heat pad.
222 Behavioural observations of transferred piglets and nurse sows were conducted for 5
223 min immediately and 1 h, 2 h and 4 h after transfer. Observations were carried out
224 using all occurrence continuous sampling (Martin *et al.*, 1993). Instances of naso-
225 naso contact (i.e. voluntary gentle touch of a piglet's snout against another's snout)

226 with the sow and/or with the other piglets, and the number of play events (i.e. nudge,
227 chase, push, push-overs, spring/leap, pivot, toss head, run, rolling (Blackshaw et al.,
228 1997; Martin et al., 2015)) were recorded and considered socially positive. The
229 number of high-pitched piglet vocalisations (i.e. screams and squeals) and escape
230 attempts from the pen were recorded as indicators of piglets' acute distress.

231

232 *Nursing behaviour.* Two entire nursing bouts were directly observed for each litter on
233 D0 (i.e. at transfer), D1, D2, D6, D9, D16 and D23. Two trained observers, not
234 blinded to treatments, carried out the observations (inter-observer reliability = 88%).
235 Because of nurse sow reluctance to nurse in the hours following transfer, the first
236 post-transfer nursing bout was observed approximately 20 h after transfer for these
237 litters. Nursing behaviour of RI, RE and 2STEP21 litters only were also observed on
238 the day preceding transfer (i.e. the day of birth for RI and RE piglets). A nursing bout
239 started when at least half of the litter massaged the udder (Andersen *et al.*, 2005),
240 accompanied by grunts from the sow. The nursing bout was considered "ended"
241 when less than half of the piglets were still active at the udder, when the sow stood
242 up or rolled to lie on her udder, or after 5 min; whichever came first. The percentage
243 of nursing bouts ended by the sow was calculated. Milk let-down and nutritive
244 nursing was considered when piglets suckled intensively for few seconds without
245 interspersing with teat massage or moving around (Heim *et al.*, 2012).

246 Teat disputes (i.e. two or more piglets trying to suckle from the same teat and biting
247 or pushing each other with their head or shoulders; De Passille and Rushen, 1989)
248 and the identity of piglets involved were recorded. This permit to calculate the
249 percentage of piglets involved in fights, the average number of fights per piglet and
250 the average number of fights per minute of nursing bout (i.e. fight intensity). The

251 number of piglets missing a nursing bout (i.e. not suckling when milk let-down
252 occurred) was recorded.

253

254 *Establishment of teat order.* Teat pairs were numbered along the udder starting from
255 anterior teats. During each observation of nursing the teat that a piglet used during
256 milk let-down was recorded to determine teat fidelity. For a given day, piglets which
257 suckled the same teat during the two nursing bouts observed received a score of 0
258 (i.e. no change) and piglets which suckled from two different teat pairs received a
259 score of 1 (i.e. change). Piglets which attended only one suckling were omitted from
260 this analysis. Then the percentage of teat changes in the litter was calculated from
261 these scores,

262 The preferred teat pair was determined for each day as the most suckled teat. Thus
263 the most preferred teat was suckled twice during two consecutive nursing bouts, or
264 once if only one nursing bout was attended. If a piglet suckled equally from two teats
265 it did not have a preferred teat. A variable “switch” was created for each pair of
266 observation days (D0-D1, D1-D3, D3-D6, D6-D9, D9-D16 and D16-D23) to assess
267 teat preference stability across days. “Switch” had a value of 1 if the piglet changed
268 preferred teat, or 0 if it did not. The percentage of changes across days was
269 calculated for each litter from these scores.

270

271 *Statistical analyses*

272 This was performed using SAS 9.4 (SAS Inst. Inc., Cary, NC). The experimental unit
273 was either the piglet (individual measures) or the sow (group measures). General
274 Linear Models (GLM) and Generalized Linear Mixed Models (GLMM) were fitted by
275 Residual Pseudo Likelihood approximation method. Statistically significant terms

276 were determined when alpha level was below 0.05, and tendencies were considered
277 when alpha level was between 0.05 and 0.1. Results are presented as means \pm
278 standard error. For overall effects of treatment and day in ANOVA (GLM and
279 GLMM), F-values and corresponding degrees of freedom (DF, in subscript) are
280 reported, and t-values and corresponding DF (subscript) are reported for pair-wise
281 comparisons. For non-parametric tests, the X^2 value and corresponding DF
282 (subscript) are reported. When parity and number of teats were relevant and had
283 significant effects on response variable, they were kept as covariates in the models.
284 Survival and “rearing failure” data were analysed using Kruskal-Wallis non-
285 parametric test (PROC NPAR1WAY). Dwass, Steel, Critchlow-Fligner method was
286 used to perform pair-wise comparisons between treatments. Data on ‘rearing failure’
287 facilitated an investigation of the risk of piglets failing to gain weight in the different
288 treatments.

289 Weights, ADGs and coefficient of variation of weights were normally distributed with
290 regards to their residuals and analysed using GLM accounting for a repeated effect
291 of day and a random effect of sow and replicate. Weights were log-transformed to
292 enhance fitness of the model; back-transformed data are reported for better
293 understanding. The analysis of pre-weaning data excluded 2STEP21 litters as these
294 piglets were approximately 7 days older than the other piglets and thus no valid
295 comparison could be made between treatments. However, post-weaning analyses
296 were conducted for all treatments. Piglets removed from an experimental sow during
297 the course of the lactation (“rearing failure” piglets) were excluded from the analysis
298 from the time point at which they were transferred.

299 Behaviour following transfer was analysed using GLMM (PROC GLIMMIX) with a
300 Poisson distribution and accounting for the repeated effect of day on sow. Analysis

301 was performed using all four observations but, given the differences between the first
302 observation and the three subsequent ones, a second analysis was performed on
303 the first observation alone. These analyses were performed only on litters reared by
304 nurse sows (1STEP21, 2STEP7 and 2STEP21).

305 Nursing behaviour variables and their residuals were normally distributed, and
306 analysed using GLMs (PROC MIXED) accounting for the repeated effect of period of
307 observation within day and sow, and the random effect of replicate and observer.

308 The variable “number of fights per piglet” was log-transformed to enhance fitness of
309 the model (back-transformed data are reported). The termination of nursing bouts
310 was analysed as a binary variable using GLMM (PROC GLIMMIX), accounting for
311 the random effect of sow.

312 The percentages of teat changes within and across days normally distributed and
313 analysed using GLMs that accounted for the random effect of replicate and for the
314 repeated effect of day. All litters were considered for the analysis of PTC during
315 lactation. The effect of transfer on the PTC of new-born piglets (i.e. RI and RE) and
316 of 7 day old piglets (i.e. 2STEP21) was assessed.

317

318 **Results**

319 *Survival and transfers*

320 There was no effect of treatment on pre-weaning live born mortality rates ($X^2=6.4$,
321 $DF=4$, $P>0.1$) or on the failure of sows to rear piglets (i.e. sum of dead and ‘rearing
322 failure’ piglets; $X^2=5.8$, $DF=4$, $P>0.2$). The average live born mortality rate was $7.3 \pm$
323 2.70 % and the average rearing failure rate was 11.7 ± 3.60 %.

324

325 *Weights and growth*

326 *Lactation.* Pre-weaning weights differed between treatments and days ($F_{18,}$
327 $_{2474}=13.02$, $P<0.001$; Table 1). 1STEP21 piglets were heavier than RI and RE piglets
328 on D0 ($t_{26.2}=5.48$ and $t_{31}=5.67$, respectively, $P<0.001$) and D1 ($t_{26.2}=4.63$ and
329 $t_{31}=6.71$, respectively, $P<0.005$). On D3 1STEP21 piglets were heavier than RE
330 piglets ($t_{31.1}=4.04$, $P<0.05$) and tended to be heavier than RI piglets ($t_{26.2}=3.62$,
331 $P<0.07$). 2STEP7 piglets were heavier than RE piglets on D0 ($t_{26.1}=4.31$, $P<0.005$).
332 Between D0 and D1, RE piglets had higher ADG than 1STEP21 piglets ($t_{33.7}=-3.52$,
333 $P<0.01$) and tended to have higher ADG than 2STEP7 piglets ($t_{33.9}=-2.50$, $P=0.09$)
334 (Table 1). 1STEP21 and 2STEP7 piglets did not differ significantly in weight
335 throughout lactation ($t_{25.7}=-0.03$, $P>0.9$). From D7 until weaning there was no
336 treatment difference in weight or ADG. The coefficient of variation (CV) of weight of
337 1STEP21 and 2STEP7 litters was lower than RI litters on D0 ($t_{258}=-5.42$ and $t_{258}=-$
338 5.35 , respectively, $P<0.001$) and D1 (i.e. $t_{258}=-4.38$ and $t_{258}=-3.88$, respectively,
339 $P<0.05$). The CV of weight in 1STEP21 and 2STEP7 litters increased gradually
340 between D0 and D24 ($P<0.05$) (Figure 1).

341

342 *Post-weaning.* There was no overall treatment effect on piglet post-weaning weight
343 ($F_{4, 29.6}=1.17$, $P>0.05$; Table 1) but there was a treatment by day interaction ($F_{8,}$
344 $_{758}=3.72$, $P<0.001$). 1STEP21 pigs were heavier than RI pigs at entry to the second
345 stage weaner accommodation ($t_{35.4}=2.88$, $P<0.01$), but this difference was not
346 significant after adjustment for multiple comparisons. Indeed, 1STEP21 pigs had a
347 higher ADG than RI pigs ($P<0.05$) during the week following weaning ($t_{24.9}=3.17$,
348 $P<0.05$; Table 1).

349

350 *Behaviour following transfer to the nurse sow*

351 No escape attempts were observed in any treatment. Piglets performed more of the
352 behaviours which were observed directly after transfer than in the following hours
353 ($P < 0.01$; Table 2). During the first observation after transfer, 2STEP7 piglets
354 performed more naso-naso contacts with each other and vocalised more than
355 2STEP21 piglets ($t_8 = 3.61$, $P < 0.01$; $t_8 = 3.89$, $P < 0.005$, respectively; Table 3). No
356 treatment difference was found in play behaviour ($F_{2,8} = 1.62$; $P > 0.2$) or the number of
357 naso-naso contacts with the sow ($F_{2,8} = 2.35$; $P > 0.01$).

358 Over all the observations, 2STEP21 piglets vocalised less ($t_{89} = 2.88$, $P < 0.05$) and
359 performed fewer naso-naso contacts with other piglets than 2STEP7 ($t_{89} = 3.11$,
360 $P < 0.01$) and 1STEP21 piglets ($t_{89} = 2.34$, $P < 0.05$) (Table 3). 2STEP7 piglets also
361 tended to have fewer naso-naso contacts with the sow than 2STEP21 piglets ($t_{89} =$
362 1.19 , $P < 0.08$, Table 3). No treatment effect was detected in play behaviour
363 ($F_{2,89} = 1.55$, $P > 0.2$).

364

365 *Nursing behaviour*

366 All variables investigated significantly decreased between D1 and D23 ($P < 0.001$)
367 except the percentage of nursing bouts ended by the sow, which significantly
368 increased ($P < 0.001$) (data not presented).

369 Overall, treatment affected the number of fights per minute ($F_{4,115} = 4.61$, $P < 0.05$;
370 Figure 2a), the percentage of piglets fighting ($F_{1,147} = 2.71$, $P < 0.05$; Figure 2b), the
371 number of fights per piglet ($F_{4,133} = 2.70$, $P < 0.05$; Figure 2c), and nursing duration
372 ($F_{4,107} = 2.72$, $P < 0.05$). The percentage of piglets missing nursing bouts tended to be
373 affected by treatment ($F_{4,140} = 1.98$, $P = 0.1$, data not presented), on average 9.4 ± 1.20
374 % of piglets missed a nursing bout. Litters reared by sows in early lactation (i.e. RI,
375 RE and 2STEP7) showed less fighting behaviour (Figure 2) and had fewer piglets

376 missing nursing bouts (8.5 ± 1.16 % vs. 10.8 ± 1.18 %; $F_{1,145}=7.22$, $P<0.001$) than
377 litters reared by sows in late lactation (i.e. 1STEP21 and 2STEP21). 2STEP21 litters
378 had shorter nursing bouts than RI (215 ± 12.8 sec vs. 258 ± 12.2 sec, $t_{107}=-2.81$,
379 $P<0.05$) and 1STEP21 litters (215 ± 12.8 sec vs. 253 ± 12.6 sec, $t_{81.7}=2.80$, $P<0.05$).
380 2STEP21 sows tended to terminate a greater percentage of nursing bouts than RI
381 sows (24 ± 6.7 % vs. 60 ± 9.3 %, $t_{595}=2.93$, $P<0.06$).

382

383 *Teat order establishment and stability*

384 Overall, PTC did not differ between treatments ($F_{4,31.5}=1.92$, $P>0.1$, Figure 3a) and
385 days ($F_{5,83.5}=1.93$, $P<0.1$). The interaction between treatment and day on PTC before
386 and after transfer of piglets was significant ($F_{2,24.2}=3.74$, $P<0.05$, Figure 3b), but pair-
387 wise comparisons were not significant ($P>0.05$). Before transfer 2STEP21 litters had
388 lower PTC than RI litters ($t_{14.9}=-5.28$) and tended to have lower PTC than RE litters
389 ($t_{11.6}=-2.77$, $P<0.1$), but after transfer there was no treatment difference in PTC
390 ($F_{2,22.8}=1.37$, $P>0.2$).

391

392 **Discussion**

393 *Effectiveness of the strategies*

394 There are many different strategies used to rear “surplus” piglets that arise from very
395 large litter sizes producing more piglets than available teats. They include split
396 (early) weaning, which contradicts the recommendations of the EU legislation (The
397 Council of the European Union, 2008), split suckling, which represents considerable
398 additional workload for the farm staff, or artificial rearing, which could have negative
399 effects on piglets’ performance and welfare (Baxter et al. 2013). There is also the
400 use of nurse sows, which, despite being an increasingly ubiquitous practice on

401 commercial farms, has received little scientific investigation into the impacts on sows
402 and piglets. This study investigated the effects of different fostering strategies on
403 piglet growth and behaviour compared to piglets remaining with their mother. Both
404 nurse sow strategies were effective in rearing one day old piglets transferred from
405 large litters. Indeed, survival and growth performance of transferred piglets was not
406 different to that of piglets remaining with their mother. However, it is important to
407 note that the heaviest and most vigorous piglets in the litter were transferred (as per
408 typical farm practice) because they are more likely to survive than their lighter
409 littermates (e.g. Baxter *et al.*, 2008; Milligan *et al.*, 2001; Tuchscherer *et al.*, 2000)
410 and thus hypothesised to be better placed to cope with the challenge of fostering
411 (Heim *et al.*, 2012). Also, as piglets with a lower birth weight seemed to be able to
412 catch up with heavier piglets at weaning/slaughter (Douglas *et al.*, 2013), leaving
413 them with their mother might promote this compensatory growth. Therefore, we did
414 not control for effect of transfer on the smallest piglets in the litter, or for the effect of
415 remaining with their mother on the heaviest piglets, and results are interpreted with
416 this caveat. Further studies should include such control groups in order to draw
417 stronger conclusions on the effectiveness of the nurse sows strategies.

418 It is also highly likely the effectiveness of any nurse sow strategy will depend on the
419 maternal abilities of the sow. In the current study “maternal ability” was determined
420 simply by selecting sows in good body condition, with at least 12 piglets and that had
421 not crushed a piglet from farrowing until selection. This proxy measure of sow
422 rearing potential is an easy way for farmers to make judgements on sows, and the
423 present study suggests it is appropriate in conventional farrowing systems. However,
424 for nurse sow strategies to be achievable (i.e. rear surplus piglets from large litters)
425 our results suggest that other characteristics may be involved. Indeed, the stage of

426 lactation and the temperament (e.g. restlessness) of the sow could influence the
427 fighting behaviour at the udder, thus affecting the growth and welfare of transferred
428 piglets. For instance, nursing behaviour of sows has been shown to correlate with
429 pre-pubertal response to behavioural tests (i.e. open field; Thodberg *et al.*, 2002),
430 and the frequency of nursing bouts has been shown to correlate negatively with
431 competition at the udder (Pedersen *et al.*, 1998).

432 More detailed measures of sow maternal abilities might be needed to validate the
433 use of nurse sows in farrowing systems where sows are loose-housed, as piglet
434 pre-weaning survival is even more reliant on maternal behaviour in such systems
435 (Ocepek and Andersen, 2017).

436

437 *Growth performance*

438 Because heaviest piglets within each litter were selected for transfer to a nurse sow,
439 1STEP21 and 2STEP7 piglets were heavier than RI and RE piglets on D0, but this
440 difference was not detectable two days after. Moreover, the coefficient of variation
441 (CV) of weight was lower in transferred litters than in remained litters on D0, but CVs
442 did not differ anymore by D10. These findings suggest that transferred piglets
443 experienced growth check during the week following transfer, and may have been
444 unable to express their full growth potential during lactation. This could be due to a
445 discrepancy between their needs and milk quality (see Hurley, 2015 for a review) or
446 to delayed nursing following transfer (i.e. no nursing was observed in the 4 h
447 following transfer). As nurse sows are usually lactating for at least 7 days, some of
448 their teats might not have been used by the previous litter and thus, had stopped
449 producing milk. Thus, it is best practise to only give a nurse sow the same number of

450 piglets or fewer piglets than what she has been suckling to ensure that piglets have
451 at least one teat each to suckle after being transferred,
452 All treatments were weaned at approximately the same age and at the same weight,
453 However, 1STEP21 pigs had an ADG twice as high as RI pigs in the first week post-
454 weaning, and thus were 2 kg heavier by 8 weeks of age. This could either be related
455 to their poor pre-weaning performance (compensatory growth), or to their higher
456 growth potential related to heavier birthweight. Also, the lower milk quality or higher
457 reluctance of the sow to milk the transferred litter could have led 1STEP21 piglets to
458 consume solid food earlier than the other treatments, which would reduce the impact
459 of changing from liquid to solid diets following weaning.

460

461 *Behaviour following transfer to the nurse sow*

462 Transferred piglets were more active directly after transfer than in the following hours
463 probably because they were exploring their new environment, the nurse sow and
464 their new littermates (i.e. for piglets in mixed litters, 1STEP21 and 2STEP7). Naso-
465 naso contacts are a means of communication between piglets and the sow
466 (Blackshaw *et al.*, 1997) and probably also between piglets. Therefore, the higher
467 occurrence of naso-naso contacts in mixed litters, compared to stable litters (i.e.
468 2STEP21), may reflect the interest that unfamiliar piglets have for one another.
469 Different piglets' vocalisations are partly indicative of their coping capacity to being
470 separated from their mother (Weary and Fraser, 1997). Thus, contradicting our initial
471 hypothesis, our results suggest that 1 day old piglets coped less well, and thus
472 experienced greater distress, with transfer than 7 day old piglets, as 2STEP21
473 piglets vocalised less than 2STEP7 and 1STEP21 piglets. Further investigation
474 should address long-term effects of transfer on social and play behaviours, since

475 early play experience pre-weaning seems to improve post-weaning social play and
476 coping with mixing at weaning (Donaldson *et al.*, 2002).

477

478 *Nursing behaviour and teat order*

479 All fighting variables recorded (i.e. number of fights per piglet, percentage of piglets
480 involved in fights, and number of fights per minute) declined gradually over time,
481 suggesting that conflicts for teat ownership were solved as time passed. However, at
482 the end of lactation (D23) there was still approximately 30% of the piglets fighting
483 over teats, 0.2 teat fights per piglet and one piglet missing the nursing bout (i.e.
484 about 13%); showing that conflicts were not fully resolved. Competition at the udder
485 increases with litter size (Andersen *et al.*, 2011), likely explaining the difference
486 between the results of the present study and previous work (Hemsworth *et al.*, 1976;
487 Puppe and Tuchscherer, 1999), where litter size was smaller and stability was
488 reached earlier (i.e. second week of lactation). Indeed, litters above ten piglets may
489 experience more difficulty in retrieving preferred teat pairs during synchronous
490 nursing bouts, suggesting higher competition (Hemsworth *et al.*, 1976). This
491 supports intervention strategies to ensure large litters do not remain as such, as
492 failure to establish teat order would result in higher competition at the udder,
493 probably accompanied by lower growth of the piglets and more lesions at the sow's
494 udder.

495 Unexpectedly, all fighting variables and PTC increased numerically at the end of the
496 lactation for all treatments. A first causation could be that the ease of udder access
497 was impaired by the farrowing crate design (Moutsen *et al.*, 2011), which was
498 narrower on one side and therefore hard to access as the piglets grew (personal
499 observation). Secondly, sows might be less willing to position correctly during

500 nursing bouts later in lactation as they initiated weaning (Pedersen *et al.*, 1998). This
501 is supported by our finding that litters reared by nurse sows in late lactation (i.e.
502 1STEP21, 2STEP21) performed more fighting behaviour, had a greater percentage
503 of piglets missing a nursing bout and shorter nursing bouts than litters reared by
504 early lactation sows (i.e. RI, RE, 1STEP7); even though 2STEP21 piglets were not
505 introduced to new piglets, and RE and 1STEP7 piglets were.

506 Despite the fact that 1STEP21 and 2STEP21 sows were both in late lactation at
507 transfer, their behaviour was subtly different during nursing bouts. Indeed, 1STEP21
508 sows had longer nursing bouts and terminated fewer of them, thus allowing the
509 piglets to spend more time massaging the udder. This suggests that the age of the
510 transferred piglets influenced nurse sows' nursing behaviour. Sows might be aware
511 of the piglets' nursing needs, probably via communication between the piglets and
512 the sow around nursing bouts (i.e. vocalisation and massaging of udder; Algers,
513 1993). In 2STEP21 litters, fostered piglets and nurse sows had bonded with their
514 previous mother and offspring (respectively) before transfer, thus re-establishing
515 communication might have required adaptation (Algers, 1993). Thus, sows seemed
516 to be able to adapt their nursing behaviour to piglets' needs. Selection of nurse sows
517 could thus include a behavioural criterion on the sows' willingness to nurse the
518 piglets and not to terminate the nursing bout.

519 Removing the heaviest piglets from large litters (i.e. RI and RE) resulted in a 30%
520 (numerical) decrease in PTC, suggesting better access to the teats, which is the
521 logical consequence of reducing litter size. Contrarily, fostering a whole litter of 7 day
522 old piglets (i.e. 2STEP21) onto a nurse sow (numerically) increased PTC by 70%,
523 likely reflecting the adaptation to the nurse sow's udder and the need to re-establish
524 teat order.

525

526 In conclusion, the present results suggest that, provided that heaviest and vigorous
527 piglets are selected to be transferred, the nurse sow strategies tested have minimal
528 implications for their performance. Although there were some negative effects with
529 regard to growth and competitive behaviour, particularly for piglets transferred to
530 sows late in lactation, these strategies represent potential management tools for
531 managing large litters on commercial farms in the absence of alternative systems.
532 However, given the small number of litters involved in the present study, these
533 results have to be considered with caution.

534

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541

542 **Declaration of interest**

543 The authors declare that they did not have a conflict of interest in the conduction of
544 this study.

545

546 **Ethics statement**

547 Ethical approval for this study was granted by Teagasc Animal Ethics Committee
548 (approval no. TAEC90/2015). The experiment was carried out in accordance with
549 Irish legislation (SI no. 543/2012) and the EU Directive 2010/63/EU for animal
550 experimentation.

551

552 **Software and data repository resources**

553 None of the data were deposited in an official repository.

554

555 **References**

556 AHDB Pork 2017. 2016 Pig cost of production in selected countries. Retrieved on 22 May
557 2018, from [https://pork.ahdb.org.uk/media/274535/2016-pig-cost-of-production-in-](https://pork.ahdb.org.uk/media/274535/2016-pig-cost-of-production-in-selected-countries.pdf)
558 [selected-countries.pdf](https://pork.ahdb.org.uk/media/274535/2016-pig-cost-of-production-in-selected-countries.pdf)

559 Algers B 1993. Nursing in Pigs : Communicating Needs and Distributing Resources. Journal
560 of Animal Science 71, 2826–2831.

561 Andersen IL, Berg S and Bøe KE 2005. Crushing of piglets by the mother sow (*Sus scrofa*) -
562 Purely accidental or a poor mother? Applied Animal Behaviour Science 93, 229–243.
563 doi:10.1016/j.applanim.2004.11.015

564 Andersen IL, Nævdal E and Bøe KE 2011. Maternal investment, sibling competition, and
565 offspring survival with increasing litter size and parity in pigs (*Sus scrofa*). Behavioural
566 Ecology and Sociobiology 65, 1159–1167. doi:10.1007/s00265-010-1128-4

567 Baxter EM, Jarvis S, D'Eath RB, Ross DW, Robson SK, Farish M, Nevison IM, Lawrence AB
568 and Edwards SA 2008. Investigating the behavioural and physiological indicators of
569 neonatal survival in pigs. Theriogenology 69, 773–783.
570 doi:10.1016/j.theriogenology.2007.12.007

571 Blackshaw JK, Swain AJ, Blackshaw AW, Thomas FJM and Gillies KJ 1997. The
572 development of playful behaviour in piglets from birth to weaning in three farrowing
573 environments. Applied Animal Behaviour Science 55, 37–49. doi:10.1016/S0168-
574 1591(97)00034-8

575 De Pastille AMB and Rushen J 1989. Suckling and teat disputes by neonatal piglets. Applied
576 Animal Behaviour Science 22, 23–38. doi:10.1016/0168-1591(89)90077-4

577 Donaldson TM, Newberry RC, Špinka M and Cloutier S 2002. Effects of early play
578 experience on play behaviour of piglets after weaning. *Applied Animal Behaviour*
579 *Science* 79, 221–231. doi:10.1016/S0168-1591(02)00138-7

580 Douglas SL, Edwards SA, Sutcliffe E, Knap PW and Kyriazakis I 2013. Identification of risk
581 factors associated with poor lifetime growth performance in pigs. *Journal of Animal*
582 *Science* 91, 4123–4132.

583 The Council of the European Union 2008. Council Directive 2008/120/EC of 18 December
584 2008 laying down minimum standards for the protection of pigs. *The Official Journal*
585 L47, 5–13. Heim G, Mellagi APG, Bierhals T, de Souza LP, de Fries HCC, Piuco P,
586 Seidel E, Bernardi ML, Wentz I and Bortolozzo FP 2012. Effects of cross-fostering
587 within 24h after birth on pre-weaning behaviour, growth performance and survival rate
588 of biological and adopted piglets. *Livestock Science* 150, 121–127.
589 doi:10.1016/j.livsci.2012.08.011

590 Hemsworth PH, Winfield CG and Mullaney PD, 1976. A study of the development of the teat
591 order in piglets. *Applied Animal Ethology* 2, 225–233. doi:10.1016/0304-
592 3762(76)90054-7

593 Hurley WL 2015. Composition of sow colostrum and milk. In: *The Gestating and Lactating*
594 *Sow* (ed. C Farmer). pp. 193–229. Wageningen Academic Publishers, Wageningen,
595 The Netherlands. doi:10.3920/978-90-8686-803-2_9

596 Martin JE, Ison SH and Baxter EM 2015. The influence of neonatal environment on piglet
597 play behaviour and post-weaning social and cognitive development. *Applied Animal*
598 *Behaviour Science* 163, 69–79. doi:10.1016/j.applanim.2014.11.022

599 Martin P, Bateson PPG, Bateson P 1993. *Measuring behaviour: an introductory guide*.
600 Cambridge University Press, Cambridge, UK.

601 Milligan BN, Fraser D and Kramer DL 2002. Within-litter birth weight variation in the
602 domestic pig and its relation to pre-weaning survival, weight gain, and variation in
603 weaning weights. *Livestock Production Science* 76, 181–191. doi:10.1016/S0301-
604 6226(02)00012-X

605 Milligan BN, Fraser D and Kramer DL 2001. The effect of littermate weight on survival,
606 weight gain, and suckling behavior of low-birth-weight piglets in cross-fostered litters.
607 Journal of Swine Health and Production 99, 161–166.

608 Moutsen VA, Lahrmann HP and D'Eath RB 2011. Relationship between size and age of
609 modern hyper-prolific crossbred sows. Livestock Science 141, 272–275.
610 doi:10.1016/j.livsci.2011.06.008

611 Muirhead MR and Alexander TJL 1997. Managing pig health and the treatment of disease: a
612 reference for the farm. 5M Enterprises Ltd., Sheffield, UK.

613 Muns R, Silva C, Manteca X and Gasa J 2014. Effect of cross-fostering and oral
614 supplementation with colostrums on performance of newborn piglets. Journal of
615 Animal Science 92, 1193-1199. doi:10.2527/jas2013-6858

616 Ocepek M and Andersen IL 2017. What makes a good mother? Maternal behavioural traits
617 important for piglet survival. Applied Animal Behaviour Science 193, 29-36.
618 doi:10.1016/j.applanim.2017.03.010

619 Pedersen LJ 2016. Large litter size and the challenges in loose housing. Proceedings of the
620 Report of the Free Farrowing Workshop 2016. Belfast, United Kingdom 320-338.
621 Retrieved on 15 May 2018, from
622 https://www.freefarrowing.org/info/2/research/45/free_farrowing_workshops.

623 Pedersen LJ, Studnitz M, Jensen KH and Giersing AM 1998. Suckling behaviour of piglets in
624 relation to accessibility to the sow and the presence of foreign litters. Applied Animal
625 Behaviour Science 58, 267-279.

626 Puppe B and Tuchscherer A 1999. Developmental and territorial aspects of suckling
627 behaviour in the domestic pig (*Sus scrofa f . domestica*). Journal of Zoology 249,
628 307-313.

629 Quesnel H 2011. Colostrum production by sows: variability of colostrum yield and
630 immunoglobulin G concentrations. Animal 5, 1546-1553.
631 doi:10.1017/S175173111100070X

632 Reese DE and Straw BE 2006. The case against evening-up litters until weaning. In
633 Nebraska Swine Reports, pp. 7-10. The University of Nebraska, Lincoln, NE,
634 USA. Rutherford K, Baxter E, D'Eath R, Turner S, Arnott G, Roehe R, Ask B, Sandøe
635 P, Moustsen V, Thorup F, Edwards S, Berg P and Lawrence A 2013. The welfare
636 implications of large litter size in the domestic pig I: biological factors. *Animal Welfare*
637 22, 199-218. doi:10.7120/09627286.22.2.199

638 Schmitt O, Baxter EM, Boyle LA and O'Driscoll K. Nurse sow strategies in the domestic pig:
639 I. Consequences on selected measures of sow welfare. Submitted to *Animal*.

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

643 Thorup F 2015. Nurse sows for super numerous piglets. Proceedings of the 1st International
644 Conference on Pig Welfare. 29-30 April 2015. Copenhagen, Denmark, 75.

645 Tuchscherer M, Puppe B, Tuchscherer A and Tiemann U 2000. Early identification of
646 neonates at risk: traits of newborn piglets with respect to survival. *Theriogenology* 54,
647 371-388. doi:10.1016/S0093-691X(00)00355-1

648 Ward PA, Blanchard RJ and Bolivar V 2008. Stress and Distress: Definitions. In *Recognition*
649 *and Alleviation of Distress in Laboratory Animals*, pp. 13–24. National Academies
650 Press, Washington, DC, USA. Newberry RC and Swanson JC 2008. Implications of
651 breaking mother-young social bonds. *Applied Animal Behaviour Science* 110, 3-23.
652 doi:10.1016/j.applanim.2007.03.021

653 Weary DM, Ross S and Fraser D 1997. Vocalizations by isolated piglets: a reliable indicator
654 of piglet need directed towards the sow. *Applied Animal Behaviour Science* 53, 249-
655 257.

656 Westin R, Holmgren N, Hultgren J and Algiers B 2014. Large quantities of straw at farrowing
657 prevents bruising and increases weight gain in piglets. *Preventive Veterinary Medicine*
658 115, 181-190.

659 **Table 1** Mean (\pm S.E.) weights (kg) and Average Daily Gain (kg/d) of new-born piglets reared by their mother in an intact litter (RI)
660 or in an equalised litter (RE), new-born piglets reared by a nurse sow 21 (1STEP21) or 7 (2STEP7) days into lactation and 7 day
661 old piglets reared by a nurse sow 21 days into lactation (2STEP21).

	RI ⁴	RE ⁵	1STEP21 ⁶	2STEP7 ⁷	2STEP21 ⁸	S.E.M	P-value
Weight (kg)							
D0 ¹	1.43 ^C	1.38 ^B	1.88 ^A	1.74 ^{AB}	.	0.020	<0.001
D1	1.59 ^B	1.56 ^B	1.99 ^A	1.86 ^{AB}	.	0.020	<0.001
D3	1.85	1.77 ^B	2.17 ^A	2.01	.	0.020	<0.001
D10	3.16	3.28	3.26	3.48	.	0.020	N.S. ⁹
D17	4.76	4.88	4.74	5.04	.	0.020	N.S.
D24	6.24	6.54	6.31	6.67	.	0.020	N.S.
Weaning (W)	7.84	8.24	8.16	8.04	7.76	1.050	N.S.
W7 ²	8.52	9.45	9.58	9.16	8.88	1.050	N.S.
S2 ³	13.54	14.50	15.94	14.01	13.74	1.050	<0.001
Average Daily Gain (kg/d)							
D0 – W	0.22	0.23	0.21	0.22	.	0.010	N.S.
D0 - D1	0.16	0.18 ^B	0.10 ^A	0.12	.	0.017	<0.01
D1 - D3	0.19	0.15	0.13	0.12	.	0.015	N.S.
D3 -D10	0.22	0.22	0.19	0.28	.	0.013	N.S.
D10 - D17	0.23	0.23	0.22	0.22	.	0.015	N.S.
D17 - D24	0.22	0.25	0.23	0.22	.	0.020	N.S.
D24 – W	0.21	0.25	0.23	0.24	.	0.015	N.S.
W - W7	0.12 ^b	0.16	0.23 ^a	0.14	0.15	0.032	<0.05
W7 - S2	0.35	0.39	0.44	0.42	0.38	0.032	N.S.

662 ¹ D0 is the day of transfer, 1 day after the birth of RI and RE piglets.

663 ² W7 stands for “7 days post-weaning” (approximately 5 weeks-old).

664 ³ S2 stands for second stage weaner accommodation (approximately 8 weeks-old).

665 ⁴ RI piglets remained with their mother in an intact litter

666 ⁵ RE piglets remained with their mother in an equalised litter (i.e. mixed with fostered piglets)

667 ⁶ 1STEP21 piglets were transferred at 1 day old onto a nurse sow 21 days into lactation

668 ⁷ 2STEP7 piglets were transferred at 1 day old onto a nurse sow 7 days into lactation

669 ⁸ 2STEP21 piglets were transferred at 7 day old onto a nurse sow 21 days into lactation^{A, a...} Different

670 superscript letters indicate significant differences (lowercase: $P < 0.05$, uppercase: $P < 0.01$)

671 ⁹ N.S. means that the effect was statistically non-significant ($P > 0.05$)

672

673 **Table 2** Mean (\pm S.E.M) number of naso-naso contacts between piglets, naso-naso
674 contacts between piglets and sow, play behaviours and vocalisations recorded
675 during the four 5-min direct observation periods following transfer of piglets to nurse
676 sows (all treatments combined; 1STEP2: 10 litters and 120 piglets, 2STEP7: 9 litters
677 and 106 piglets and 2STEP21: 9 litters and 108 piglets). The first observation was
678 performed directly after transfer of piglets to the nurse sow and subsequent
679 observations were performed 1h, 2h and 4h after.

Time since transfer (h)	0	1	2	4	P-value
Naso-naso contacts between piglets	7.2 ^A (\pm 1.46)	1.1 ^B (\pm 0.27)	1.0 ^B (\pm 0.25)	1.0 ^B (\pm 0.25)	<0.001
Naso-naso between piglets and sow	7.8 ^A (\pm 1.25)	0.4 ^B (\pm 0.12)	0.5 ^B (\pm 0.15)	0.4 ^B (\pm 0.13)	<0.001
Play	3.9 ^A (\pm 0.70)	0.6 ^B (\pm 0.16)	0.9 ^B (\pm 0.21)	1.0 ^B (\pm 0.23)	<0.005
Vocalise	2.6 (\pm 0.65)	1.1 (\pm 0.30)	1.4 (\pm 0.37)	1.7 (\pm 0.43)	N.S. ¹

680 ^{A, B, ...} Different superscript letters indicate significant differences (P<0.005).

681 ¹ N.S. means that the effect was statistically non-significant (P>0.05)

682 **Table 3** Mean (\pm S.E.M) number of naso-naso contacts between piglets, naso-naso
683 contacts between piglets and sow, play behaviours and vocalisations recorded
684 during the 5-min direct observations following transfer of piglets onto the nurse sow.
685 There were 10 1STEP21 litters observed (n=120 piglets), 9 2STEP7 litters (n=106
686 piglets) and 9 2STEP21 litters (n=108 piglets).

Variable	1STEP21 ¹	2STEP7 ²	2STEP21 ³	P-value
All observations				
Naso-naso piglet-piglet	2.4 ^a (\pm 0.57)	2.3 ^a (\pm 0.57)	1.0 ^b (\pm 0.30)	<0.05
Naso-naso piglets - sow	0.7 (\pm 0.20)	1.0 (\pm 0.27)	1.4 (\pm 0.33)	N.S. ⁴
Play	1.0 (\pm 0.28)	1.7 (\pm 0.40)	1.6 (\pm 0.38)	N.S.
Vocalise	1.9 (\pm 0.55)	2.9 ^a (\pm 0.78)	1.2 ^b (\pm 0.40)	<0.05
First observation				
Naso-naso piglet-piglet	9.2 (\pm 2.82)	8.3 ^a (\pm 2.70)	4.4 ^b (\pm 1.50)	< 0.05
Naso-naso piglets - sow	6.0 (\pm 1.50)	8.1 (\pm 2.04)	10.5 (\pm 2.56)	N.S.
Play	3.5 (\pm 0.76)	5.6 (\pm 1.11)	4.2 (\pm 0.90)	N.S.
Vocalise	3.3 (\pm 1.31)	2.8 ^a (\pm 1.22)	0.9 ^b (\pm 0.44)	<0.05

687 ^{a, b, ...} Different superscript letters indicate significant differences (P<0.05).

688 ¹ 1STEP21 piglets were transferred at 1 day old onto a nurse sow 21 days into lactation

689 ² 2STEP7 piglets were transferred at 1 day old onto a nurse sow 7 days into lactation

690 ³ 2STEP21 piglets were transferred at 7 day old onto a nurse sow 21 days into lactation

691 ⁴ N.S. means that the effect was statistically non-significant (P>0.05)

692 **Figure 1** Mean (\pm S.E.) coefficient of variation to the mean litter weight in litters of
693 new-born piglets reared by their mother in an intact litter (RI) or in an equalised litter
694 (RE), new-born piglets reared by a nurse sow 21 (1STEP21) or 7 (2STEP7) days
695 into lactation and 7 day old piglets reared by a nurse sow 21 days into lactation
696 (2STEP21). D0 was the day of transfer of new-born piglets onto the nurse sow, and
697 D01, D03, D10 and D17 are the days relative to D0. ^{a,b} Different superscript letters
698 indicate significant differences ($P < 0.05$)

699

700 **Figure 2** Fighting behaviours of piglets during nursing bouts in litters of new-born
701 piglets reared by their mother in an intact litter (RI) or in an equalised litter (RE),
702 new-born piglets reared by a nurse sow 21 (1STEP21) or 7 (2STEP7) days into
703 lactation and 7 day old piglets reared by a nurse sow 21 days into lactation
704 (2STEP21). (a) Number of fight per minute, (b) Percentage of piglets fighting, (c)
705 Number of fights per piglet. Different superscript letters indicate significant difference
706 (^{a,b} lowercase: $P < 0.05$; ^{A,B} uppercase: $P < 0.001$).

707

708 **Figure 3** (a) Mean (\pm S.E.M.) percentage of teat changes in litters with: new-born
709 piglets reared by their mother in an intact litter (RI) or in an equalised litter (RE),
710 new-born piglets reared by a nurse sow 21 (1STEP21) or 7 (2STEP7) days into
711 lactation and 7 day old piglets reared by a nurse sow 21 days into lactation

712 (2STEP21). (b) Mean (\pm S.E.M.) percentage of teat changes before and after transfer
713 to the nurse sow of RE, RI and 2STEP21 piglets. ^{a,b} Different superscript letters
714 indicate significant difference ($P < 0.05$).

715