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Temporary crate opening procedure affects immediate post-opening piglet mortality and sow behaviour

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Short title: Crate opening procedure affects piglet mortality

Abstract

Producers are interested in utilising farrowing systems with reduced confinement to improve sow welfare, however concerns of increased mortality may limit commercial uptake. Temporary confinement systems utilise a standard crate which is opened 3-7 days post-partum, providing protection for neonatal piglets at their most vulnerable age and later increased freedom of movement for sows. However, there is anecdotal evidence that piglet mortality increases immediately after the temporary crate is opened. The current study aims were to determine if piglet mortality increases post-opening, to trial different opening techniques to reduce post-opening piglet mortality and to identify how the different opening techniques influence sow behaviour. Three opening treatments were implemented across 416 sows: two involved opening crates individually within each farrowing house when each litter reached seven days of age, in either the morning or afternoon (AM or PM), with a control of the standard method used on the farm to open all crates in each farrowing house simultaneously once the average litter age reached seven days (ALL). Behavioural observations were performed on five sows from each treatment during the six hours after crate opening, and during the same six hour period on the previous and subsequent days. Across all treatments, piglet mortality was significantly higher in the post-opening than pre-opening period (*P* < 0.0005). Between opening treatments, there were significant differences in piglet mortality during the two days after crate opening (*P* < 0.05), whilst piglet mortality also tended to differ from crate opening until weaning (*P* = 0.052), being highest in ALL and lowest in PM. Only sows in the PM treatment showed no increase in standing behaviour but did show an increased number of potentially dangerous posture changes after crate opening (*P* = 0.01), which may be partly attributed to the temporal difference in observation periods. Sow behaviour only differed between AM and ALL on the day before crate opening, suggesting the AM treatment disrupted behaviour pre-opening. Sows in AM and PM treatments showed more sitting behaviour than ALL, and therefore may have been more alert. In conclusion, increases in piglet mortality after crate opening can be reduced by opening crates individually, more so in the afternoon. Sow habituation to disturbance before crate opening may have reduced post-opening piglet mortality, perhaps by reducing the difference in pre- and post-opening sow behaviour patterns.

Keywords: Pig, welfare, crushing, farrowing, temporary confinement

Implications

Temporary confinement systems may be a commercially viable alternative to farrowing crates that can improve sow welfare. However, piglet mortality remains a welfare and economic concern for such systems. Knowledge of how the crate opening procedure affects piglet mortality and sow behaviour will enable stockpersons to manage these systems more effectively to reduce piglet mortality. This will contribute to improving the viability of temporary confinement systems, increasing commercial uptake and potentially improving the welfare of breeding sows globally that are currently housed in farrowing crates throughout lactation.

Introduction

The prolonged confinement of sows in crates during farrowing and lactation remains common practice across commercial indoor breeding units. The confinement of sows in crates has severe implications for sow welfare, such as restricting the capacity to turn around, perform pre-partum nesting behaviours and maintain attachment with the litter (Pedersen *et al.*, 2013; Melišová *et al.*, 2011), resulting in increased physiological stress for the sow (Jarvis *et al.*, 2006). However, farrowing crates were primarily introduced to improve piglet welfare by protecting new-born piglets from fatal or injurious crushing. Whilst a greater respect for the biological needs of the sow during farrowing and lactation is required to improve welfare standards (Baxter *et al.*, 2011), the safety of piglets from injury and death must also be considered. Although more recent studies on commercial farms suggest total piglet mortality can be comparable between confined and unconfined farrowing systems (Weber *et al.,* 2007; KilBride *et al.,* 2012), concerns remain that piglet mortality may worsen in less confined farrowing systems (Farm Animal Welfare Committee, 2015).

Considering that the majority of piglet mortality occurs during the first 48-72 hours post-partum, and over 80% within the first seven days (Marchant *et al.,* 2000; KilBride *et al.,* 2012), confining the sow beyond this period may not be of significant benefit for piglet survival. Therefore temporary confinement systems, consisting of an openable crate within individual farrowing pens, can be used to protect the neonates immediately post-partum. After this period, the crate is opened to provide additional space for the sow, providing a compromise between the needs of the farmer, the sow and her piglets. Whilst temporary confinement systems can reduce early piglet mortality in comparison to no confinement (Moustsen *et al.*, 2013; Hales *et al.*, 2015; Chidgey *et al.*, 2015), anecdotal reports from commercial farms suggest piglet mortality increases during the first 24 hours immediately after crate opening. In order to improve animal welfare, along with the economic viability and commercial uptake of temporary confinement systems, it is necessary to understand if the immediate post-opening period (24-48 hours after crate opening) creates a higher risk of piglet mortality and, if so, to identify suitable interventions to reduce the impact of crate opening.

The way in which crates are opened may cause different amounts of disturbance to the sow and litter, in turn affecting their immediate post-opening behaviour. Increased disturbance from human activity may cause increased restlessness (Chaloupková *et al.,* 2008), and therefore increase the incidence of dangerous posture changes and the subsequent risk of accidental piglet crushing. Sows are also responsive to the vocalisations of trapped piglets, especially in less confined systems (Melišová *et al.*, 2014). However, sows which respond excessively to the distress vocalisations of piglets in neighbouring litters risk causing unnecessary injuries within their own litter (Baxter *et al.*, 2011). Therefore, as we expected crushing incidence to increase post-opening, it was hypothesised that opening crates individually would reduce behavioural disturbance by minimising the peak contagion effect of sow responsiveness to crate opening and piglet vocalisations. It was also hypothesised that opening crates in the afternoon, immediately before stockpersons left for the day, would evoke a shorter sow response period as there would be no subsequent stockperson disturbance, and opening is performed closer to night-time when lights are dimmed and sows perform fewer posture changes (Hales *et al.*, 2016).

The current study aimed to determine a) if piglet mortality increases immediately after, compared to immediately before, crate opening; b) if crate opening procedure affects post-opening piglet mortality; and c) if crate opening procedure affects sow behaviour. Knowledge of these outcomes will enable the most efficient opening procedure within temporary confinement systems to be adopted, and may identify which sow behaviours are associated with increased piglet mortality.

Material and methods

Animals and dry sow management

The experiment was conducted on a commercial pig breeding unit in the north east of England. The farm consisted of 1 300 Camborough (Genus PIC, Basingstoke) breeding gilts and sows bred with Hampshire semen. During gestation, all animals were kept in straw pens in groups according to age, for gilts, or by size for multiparous sows. The farm utilised 250 farrowing places; 168 of which were temporary crate accommodation used for this study (360^{0} Freedom Farrower™, Midland Pig Producers, Burton-on-Trent). The date of moving into the farrowing accommodation and farrowing date were recorded for inclusion in statistical models.

Farrowing sow housing and management

Each farrowing pen contained a stainless steel crate (closed=2.55m x 0.90m, open=2.55m x 1.50m) within a 2.55m x 1.80m pen (Figure 1a). Each pen had plastic slatted flooring with a solid sow lying area containing drainage slots plus a 1.80m x 0.40m hot water heat pad along one side of the pen as the piglet resting area. Of the 168 temporary crates, 120 were located in six “Portapig” cabins containing 20 farrowing places each (cabins) and a further 48 were in a converted farrowing house of three rooms containing 16 farrowing places each (rooms), with pen arrangement, and therefore crate opening procedure, differing between cabins and rooms (Figures 1b and 1c, see Supplementary Figure S1 and S2 for images of pen arrangement). To open the crate, a lever on one side released the crate side to be manually adjusted vertically, whilst the other side was released to drop open obliquely. In the cabins, one person had to lean over each crate to operate the lever, allowing both persons to push the far side of the crate open before releasing the drop down side closest to the passageway. In the rooms, each crate was opened by two stockpersons, one in the central and one in the side passageway, without the need to lean over each crate.

The temporary crates were closed from entry into the farrowing house at approximately 2-5 days pre-partum. No sows had artificial induction of farrowing. Farrowing houses were kept at 22 ± 1°C, with the heat pad kept at 36°C. Farrowing house temperature gradually reduced automatically to 18 ± 1°C by day ten post-partum and to 16 ± 1°C by weaning, whilst heat pad temperature reduced to 30°C by weaning. Farrowing houses were ventilated via a central extractor fan and had full artificial lighting during working hours (05:30-14:30), with dimmed lighting outside of these hours.

Sows were fed once daily in the morning until all sows in the farrowing house had farrowed, after which sows were fed twice a day (commencing 05:30 and 13:30; diet contained 15.98% CP, 13.69 DE MJ/Kg). Cabins were hand fed via a Groba Ad-Lib feeder above the trough (Finrone Systems Ltd, Londonderry), whilst rooms contained a semi-automatic system (www.360farrower.com) feeding all sows simultaneously. Feed was gradually increased from 2kg to 10kg per sow per day during lactation. Sow drinkers were located inside the feed trough, with smaller piglet drinkers provided at the front of the pen on the opposite side to the heat pad (see Figure 1a).

Piglet management and procedures

In accordance with veterinary recommendation, piglets were tail docked, teeth clipped, and injected with 1ml of Gleptosil (Ceva Animal Health Ltd, Amersham) and 0.5ml of Betamox (Norbrook Laboratories Ltd, Newry) within 24 hours of birth. The placentae and deceased piglets were removed, with live litter size equalised for both piglet number and size by cross-fostering piglets of a similar age.

Super Dry Klenz powder (A-One Feed Supplements Ltd, Thirsk) was distributed across each pen daily. Additional dish drinkers with water were provided for smaller or weaker litters, and were removed before crate opening. A handful of creep feed (Primary Diets, AB Agri Ltd, Peterborough; followed by Flat Deck, A-One Feed Supplements Ltd, Thirsk) was provided once daily on the heat mat from approx. ten days of age until weaning. The farm's management routines included piglet fostering throughout lactation as necessary to ensure piglet and litter sizes remained similar.

Experimental design

The study compared three different crate opening treatments. The standard procedure on the farm of opening all crates within each house on the same morning when average litter age reached seven days (ALL) remained as a control treatment. Alternatives investigated in the experiment involved crates being opened individually when each litter reached seven days of age, either in the morning (AM) or afternoon (PM). Crate opening occurred at 08:30-09:30 in the AM and ALL treatments, and 13:30-14:30 for the PM treatment. All sows in a farrowing house were allocated the same crate opening treatment, which was alternated per batch, according to a balanced design to control for farrowing house effects.

Due to researcher absence, the final treatment allocations were split across two batches; cabin one, cabin two and cabin three data were collected from batch three whilst data for the remaining locations were collected in batch four. Data from any crates which were not opened within two days of the expected opening date due to poor performing litters deemed at greater risk of crushing (n=19), crates being opened and subsequently closed due to sow aggression towards stock people (in the cabins only, due to the close proximity of sows to the central passageway; n=2), and from sows which farrowed later than expected and had to be relocated to a different room to better match litter ages for weaning, were removed from the study.

Piglet mortality study

Sow identity, sow parity, farrowing location, farrowing date and the number of live-born and stillborn piglets were recorded post-partum. Four days later, the frequency and cause of piglet mortality since farrowing, as identified by the stockperson (categorised as crushed, low viability or other), and current litter size were recorded. Recording sheets were attached above each pen specifying the day and time (AM or PM) of crate opening, and for the researcher to record piglet mortality during the five day period around crate opening (two days before crate opening, day of opening and two days following crate opening). After this period, additional piglet mortality, weaning date and litter size at weaning were recorded via stockperson records.

Sow behaviour study

Sow behaviours were investigated for a subset of five sows from each treatment across three batches housed in one of the converted rooms. CCTV cameras (Gamut Professional Sony Effio E Bullet CCTV Camera 700 TV Line, 15m Infrared Night Vision (Gamut, Open24 seven Ltd, Bristol, UK)) were installed above six pens, with the same six crates observed for each batch. Cameras recorded continuously from two days before until two days after temporary crate opening. From the video recordings, time of crate opening was identified and continuous sampling of sow behaviour (Table 1) was performed for the subsequent six hours. The same six hour period was then analysed during the day before and day after crate opening.

The frequencies, total durations and average durations were calculated for each posture (average duration results described in Supplementary Material S1, Figure S3 and Table S1). The incidence and cause of piglet crushing, whereby a piglet became trapped by the sow by any means, was recorded as either fatal or non-fatal.

Statistical analysis of results

The time periods of primary interest were the two days before (‘pre-opening’; days 5-7 post-partum) and the two days after (‘post-opening’; days 7-9) temporary crate opening, in order to determine and compare the risk of piglet mortality for these time periods. Analyses were also performed for piglet mortality after the post-opening period until weaning (‘late’; days 10-27), the early post-partum period (‘early’; days 0-4), from parturition until crate opening (‘before’; days 0-7), from crate opening until weaning (‘after’; days 7-27) and the entire lactation (‘total’; days 0-27).

Piglet mortality data were analysed using the GLIMMIX procedure in SAS 9.4. The base model included the variable total born litter size and the fixed effects of treatment, housing type (cabin or room), batch (1-4), sow parity (1,2,3,4,5,6+), the number of days between housing and farrowing (0-1, 2-5, 6-7, 8+), litter age at opening (in days; <7,=7,>7), and whether or not a litter had been cross-fostered to consist of all the smallest piglets in that batch (“smalls” based on routine visual inspection and cross-fostering performed by farm staff) were included for all periods of investigation. The variable litter size on day five was included in all models except for the ‘early’ and ‘before’ time periods, whilst the continuous variable of litter age at weaning was only included for ‘late’, ‘after’ and ‘total’ piglet mortality models. Due to a chance uneven distribution of total born litter size across the treatments, the interaction of total born and treatment was included for all time periods to correct for this effect. All models used a Poisson distribution, with explanatory variables eliminated in a step-wise manner to create the final models including all variables with a P value < 0.10.

Sow behaviour data were analysed in SAS 9.4 using the PROC MIXED procedure. Sow was included as a repeated factor whilst pen number and whether a day was on the weekend or not (yes/no; to control for reduced stockperson contact during weekends) were used as random factors. Current litter size was included as a continuous variable, with day, treatment, sow parity (1, 2-5, 6+), treatment*day and parity*day as fixed effects. Explanatory variables were eliminated in a step-wise manner to create the final models including variables with a P value < 0.10, whilst day, treatment and the interaction of treatment and day were forced into all final models.

Results

Piglet mortality study

Data were included from 416 sows (ALL= 145; AM= 134; PM= 137), with a mean sow parity of 3.48 ± 0.11 (range 1-11; ALL= 3.29 ± 0.19; AM= 3.71 ± 0.18; PM= 3.47 ± 0.18). Mean total born litter size was 14.25 ± 0.14 piglets, consisting of 13.72 ± 0.14 live-born and 0.53 ± 0.05 stillborn piglets. Mean litter age at crate opening was 7.36 ± 0.06 days, whilst some crates were opened later than scheduled due to a reliance on stockperson assistance to open crates (ALL = 7.52 ± 0.16 days, range 4-13 days; AM = 7.41 ± 0.06 days, range 7-9 days; PM = 7.15 ± 0.04 days, range 7-9 days).

Piglet mortality risk throughout lactation. A total live-born piglet mortality of 574 piglets was recorded from 5,708 live-born piglets, with a mean live-born piglet mortality of 1.38 ± 0.08 piglets per litter. Total born piglet mortality to weaning was 13.38%, consisting of 10.06% of live-born and 3.69% of stillborn deaths.

Of the live-born piglet mortality, 60.45% occurred during early lactation (days 0-4), 4.88% during pre-opening (days 5-7), 11.15% during post-opening (days 7-9) and 23.52% during later lactation (day 10 until weaning). In terms of piglet mortality per litter (mortality/litter): early = 0.834 ± 0.062, pre-opening = 0.067 ± 0.014, post-opening = 0.154 ± 0.022 and late = 0.325 ± 0.030. Adjusting these estimates for the number of days per time period, piglet mortality per litter per day (mortality/litter/day) were calculated as 0.167 for early lactation, 0.034 during pre-opening, 0.077 during post-opening and 0.018 during later lactation. Combining all opening treatments, mortality/litter was significantly higher during the post-opening than pre-opening period ($P < 0.0005$; Wilcoxon signed rank test).

Effect of crate opening treatment and housing type. Treatment had a significant effect on piglet mortality during post-opening ($P < 0.05$), and therefore the after opening period ($P = 0.052$), being highest for treatment ALL, followed by AM then PM (Figure 2a). Piglet mortality was also affected by the housing type, being significantly higher in the rooms than the cabins during pre-opening ($P < 0.01$), late ($P < 0.05$) and therefore the total lactation ($P < 0.05$; Figure 2b).

Effect of days until farrowing and litter age at opening. The number of days between housing and farrowing affected piglet mortality during late lactation ($P < 0.05$), and therefore after opening ($P < 0.05$). During late lactation, piglet mortality was significantly higher for sows housed 0-1 days pre-partum (0.45 ± 0.07) than sows housed 2-5 days (0.28 ± 0.06; $P < 0.05$) or 8+ days (0.22 ± 0.05; $P < 0.01$), but not 6-7 days pre-partum (0.38 ± 0.06); whilst late piglet mortality was also significantly lower for sows housed 8+ days than 6-7 days pre-partum ($P < 0.05$). Litter age at crate opening had no significant effect on piglet mortality during any stage of lactation.

Effect of litter characteristics and sow parity. Piglet mortality increased with increasing live born litter size during the early ($P < 0.0001$), before ($P < 0.01$), late ($P < 0.01$), after opening ($P < 0.001$) and total lactation periods ($P < 0.0001$); however piglet mortality decreased with increasing total born litter size during the post-opening period ($P < 0.01$). A larger litter size on day five post-partum was associated with lower total piglet mortality ($P < 0.001$), but tended to result in higher pre-opening ($P = 0.058$) and post-opening piglet mortality ($P = 0.061$). Piglet mortality was significantly higher within the cross-fostered litters of 'small' piglets during the early ($P < 0.0001$), before ($P < 0.0001$), pre-opening ($P < 0.05$) and total lactation ($P < 0.0001$). Sow parity affected post-opening piglet mortality ($P < 0.05$), being significantly higher for parity six plus sows (0.26 ± 0.06) than parity one (0.11 ± 0.04; $P < 0.05$), two (0.09 ± 0.03; $P < 0.05$), or four (0.07 ± 0.03; $P < 0.01$), and tending to be higher than parity three (0.13 ± 0.04; $P = 0.067$) and five (0.11 ± 0.05; $P = 0.052$).

Sow behaviour study

Incidence of piglet crushing. There were no incidents of fatal crushing within video-recorded litters, and only seven non-fatal crush incidents (one stand-to-lie, one lateral-to-ventral, two ventral-to-lateral and three standing on piglet), therefore further analyses on piglet crushing could not be performed.

Sow carefulness during stand-to-lie. Although treatment or day had no effect, frequency of sniffing or rooting piglets before lying tended to be higher for parity 2-5 sows (2.02 ± 0.30) than both parity 6+ sows (0.95 ± 0.41, P = 0.054) and gilts (1.10 ± 0.40, P = 0.088). There were no significant effects of day, treatment or parity on the percentage of sniffing or rooting piglets.

Frequency of using support structures during stand-to-lie was significantly affected by treatment (P < 0.05), being lower in PM (1.77 ± 1.08) than both AM (3.94 ± 1.06; P < 0.01) and ALL (3.29 ± 1.02; P < 0.05). However, the percentage of stand-to-lie posture changes where support was used was unaffected by treatment or day. Moreover, the percentage of lying events using support was lower amongst gilts (33.6% ± 12.8) than parity 2-5 sows (51.0% ± 12.0, P < 0.05) and parity 6+ sows (56.5% ± 14.4, P = 0.061).

Frequency of dangerous posture changes. The frequency of dangerous posture changes are shown in figure 3a. Treatment tended to affect the frequency of stand-to-lie (P = 0.084), and within the treatment x day interaction, frequency of stand-to-lie was significantly higher on the day before crate opening for ALL than AM and PM (both P < 0.05). Treatment tended to affect the frequency of sit-to-lie posture changes (P = 0.069), and within the treatment x day interaction, frequency of sit-to-lie was significantly higher for PM on the day of crate opening than both AM (P < 0.05) and ALL (P < 0.01), and remained higher than AM on the following day (P < 0.05). Sow parity tended to affect the frequency of stand-to-lie posture changes (P = 0.070), being higher amongst parity 2-5 sows (7.39 ± 0.72) than parity 1 sows (5.44 ± 0.84; P < 0.05) and parity 6+ sows (5.30 ± 1.00; P = 0.077).

Frequency of turning around was significantly higher on the day of crate opening (13.68 ± 1.42) than the day after (7.88 ± 1.42; $P < 0.01$). Frequency of turning tended to differ across treatments ($P = 0.078$), being significantly higher for AM (10.02 ± 1.56) than PM (4.85 ± 1.56; $P < 0.05$), but not ALL (6.65 ± 1.42). Frequency of turning also tended to be affected by sow parity ($P = 0.074$), with parity 6+ sows (4.09 ± 1.69) turning significantly less frequently than parity 1 sows (10.01 ± 1.69; $P < 0.05$), but not parity 2-5 sows (7.42 ± 1.24).

Total duration of postures. Total durations of postures are displayed in Figure 3b. Standing duration was significantly affected by day ($P < 0.0001$), being higher on the day of opening than the day before ($P < 0.0001$) or after ($P = 0.01$). Total standing duration differed between treatments ($P < 0.01$), being significantly higher in AM than PM ($P < 0.001$), whilst total standing duration in ALL tended to be both lower than AM ($P = 0.055$) and higher than PM ($P = 0.068$). Total sitting duration tended to differ across treatments ($P = 0.082$), being lower in ALL than both AM ($P < 0.05$) and PM ($P = 0.088$).

Total duration of lateral lying tended to be affected by treatment ($P = 0.054$), being significantly lower in AM than PM ($P < 0.05$); whilst total duration of ventral lying was not affected by day or treatment. Total duration of lying (ventral + lateral) was affected by day ($P < 0.001$), being lower on the day of opening than both the day before ($P = 0.0001$) and day after ($P < 0.05$), whilst the day before and day after crate opening also tended to differ ($P = 0.055$). Total duration of lying was also affected by treatment ($P < 0.01$), being lower for AM than both PM ($P < 0.01$) and ALL ($P < 0.05$).

Sow parity had a significant effect on the total duration of both ventral and lateral lying (both $P < 0.05$). Parity 2-5 sows had both a lower total duration of lateral lying (211mins ± 25) and higher total duration of ventral lying (91.4mins ± 8.5) than parity 1 sows (lateral= 258mins ± 27; ventral= 53.5mins ± 10.5; both $P < 0.01$), but not parity 6+ sows (lateral= 241mins ± 27; ventral = 70.9mins ± 11.4).

Riskiness of rolling behaviour. Across treatments, the frequency of same side and opposite side rolling were affected by day (both: $P < 0.05$), whilst the treatment x day interaction showed a significant increase of same and opposite side rolling on the day of crate opening than the day before within PM only (Figure 4). The frequency of standing between rolling was significantly higher in ALL than PM on the day before crate opening ($P < 0.05$; Figure 4).

Discussion

To our knowledge, this is the first study to specifically measure the immediate effect of temporary crate opening on piglet mortality. The results show that piglet mortality was significantly increased after crate opening, confirming our initial hypothesis that the post-opening period is a particularly dangerous time for piglet losses. Consequently, farms may wish to implement additional measures to reduce piglet mortality during the post-opening period, such as increased supervision (Kirkden *et al.*, 2013). Whilst no post-mortem examinations were performed in the current study, it is reasonable to assume that any significant differences in piglet mortality between the pre- and post-opening periods resulted from crushing, as crate opening was the only change to occur within this time period.

There are numerous potential causes for this increase in piglet crushing. Firstly, based on the principle of why confining sows reduces crushing, crate opening eliminated the physical restriction of sow body movements. Subsequently, posture changes may be less controlled and therefore faster (Weary *et al.*, 1996), increasing the risk of crushing as piglets have less time to escape. Secondly, sows adapt their behaviour to their environment, therefore a sudden change may be stressful and require acclimation (Chidgey *et al.*, 2015). Sow behavioural adaption to farrowing crates and pens has been shown between successive parities (e.g. Jarvis *et al.*, 2001; Thodberg *et al.*, 2002), therefore the sow's ability to adapt and cope may be a gradual process unsuitable for sudden environmental changes occurring mid-lactation. Finally, not only does crate opening increase the proportion of the pen accessible to the sow, but it also decreases the proportion of the pen providing a safe resting area for the piglets. Therefore, piglets may also be required to adapt their behaviour in response to crate opening. Furthermore, as many temporary confinement systems, including the one used in the current study, are designed to use the same floor space as a traditional farrowing crate, there may be minimal safe space available to the piglets after crate opening, especially towards weaning age when piglets are larger.

Despite piglet mortality increasing in response to crate opening, total live-born piglet mortality in the current study was lower than the national average for UK indoor breeding herds (10.1% vs. 11.9% respectively; Agriculture and Horticulture Development Board Pork, 2017), the majority of which use conventional farrowing crates. Some farm surveys have shown that, whilst piglet mortality from crushing may be higher in free farrowing systems, piglet mortality from other causes is higher in crated systems, resulting in no overall difference (Weber *et al.,* 2007; KilBride *et al.,* 2012). In contrast, previous studies comparing free farrowing and temporary confinement within the same farm indicate significantly reduced total piglet mortality in the latter (Hales *et al.*, 2015; Chidgey *et al.*, 2015). However, unconfined farrowing systems were relatively new to both the farm staff and sows in these studies, which is likely to increase piglet mortality as stockpersons develop appropriate management routines. Furthermore, changing the farrowing environment of the sows in successive parities can also increase piglet mortality (King *et al.*, *submitted*). In the current study, the temporary confinement system had been in use on the farm for more than one year before the study commenced. However, the farm utilised multiple farrowing systems, therefore the previous farrowing system of individual sows would have differed.

Across all crate opening treatments, sow behaviour changed in response to crate opening. However, behaviour on the following day was more analogous to the day before crate opening, suggesting that the novelty of being released from confinement may have been the predominant cause for post-opening behavioural changes. These acute behavioural changes may also explain why piglet mortality was higher in the post-opening period than later lactation. We also measured the riskiness of sow rolling behaviour, as ventral-to-lateral rolling is an important posture change for piglet crushing in free farrowing systems (Weary *et al.*, 1996) and previous studies have found piglet crushing in free farrowing systems to be explicitly caused by rolling from one side to the other (Bradshaw and Broom, 1999; Marchant *et al.*, 2001). During observation periods, no opposite side rolling occurred on the day before, whilst eight of the fifteen sows performed opposite side rolling on the day of crate opening.

The different crate opening procedures also resulted in differences in piglet mortality and sow behaviour. Whilst the PM treatment resulted in the lowest piglet mortality, it was also the only treatment with a significant increase in post-opening dangerous posture changes. However, PM posture changes on the pre-opening day were lower than the other treatments, meaning a significant increase was more likely. As behavioural observations were only performed for six hours after crate opening, the different behaviour of PM sows may be due to a temporal difference in observation periods, including the lower level of human disturbance, rather than a temporal difference in crate opening. Increased sitting behaviour is associated with motivational conflict (Jarvis *et al.*, 1997), which in the current study, may indicate PM sows were conflicted between continuing to rest or to actively explore the open pen. This would also explain why the standing duration of PM sows did not significantly increase during the post-opening period, unlike both AM and ALL. The increased sitting behaviour of PM sows may also mean an increased alertness, as sows will often sit when disturbed by external events whilst resting, and increased sow alertness could reduce the risk of piglet crushing. Furthermore, the majority of piglet mortality from crushing is not from the immediate trauma, but rather suffocation, as the risk of a crushing incident being fatal increases with increasing duration of time trapped underneath the sow (Weary *et al.*, 1996). Therefore, whilst increased posture changes may increase the frequency of crushing, fewer crushing events would have a fatal conclusion.

Piglet mortality was also lower in the AM than ALL treatment, whilst significant differences were also observed between AM and ALL sow behaviour, but only on the day before crate opening. Whilst opening the crates individually may have avoided a simultaneous peak of post-opening sow activity, sows with younger litters could have been disturbed during the pre-opening period. This could have resulted from either the action of stockpersons opening neighbouring crates of older litters, or the subsequent post-opening increased activity of these sows. However, this pre-opening disturbance of AM sows resulted in a less profound change between preand post-opening behaviour in comparison to ALL sows. This could explain the reduced post-opening mortality, as piglets may have become more cautious of the restless sow whilst she was still in confinement. The increased pre-opening activity in AM sows could be a sign of stress or frustration (Jarvis *et al.*, 2001), and may have a welfare implication for future investigation. Furthermore, if additional measures to minimise piglet mortality, such as increased supervision, were implemented during the post-opening period; these would be more efficient if all crates were opened on the same day instead of across several days.

Finally, the different housing types used on the farm resulted in different piglet mortality outcomes, being higher in the converted rooms than the cabins during the pre-opening and later lactation periods. Unlike the cabins, pen arrangement in the rooms meant sows had extensive visual contact with other sows in adjacent pens, as well as the opportunity for physical interactions once the crates were opened. This increased sow-sow contact in the rooms may have caused prolonged disturbance, causing increased piglet mortality in later lactation, whilst having no significant effect during the post-opening period as all sows would have been aroused regardless of pen arrangement. Furthermore, as mentioned previously, a change of farrowing system can also increase mortality. The farm in the current study used multiple farrowing systems, however it would have been more likely that sows in the cabins would have farrowed in the cabins previously, due to the larger number of farrowing places in this arrangement (120 in cabins vs. 48 in rooms).

A repeat of the current study in a more controlled environment and with a larger sample size, especially for behavioural observations, would be beneficial for validating the results. In particular, a clearer differentiation between the effects of batch vs single opening, and time of day would be beneficial. It would be recommended for behavioural observations to be performed across the 24-hour period to determine the full extent of behaviours affecting piglet mortality. Future research should determine precisely how many hours or days that piglet mortality is increased, and sow behaviour is altered, after temporary confinement crates are opened. Furthermore, crate opening treatment, including time of day, and pen arrangement should be further explored for their effects on piglet and sow welfare.

In conclusion, the period following crate opening in temporary confinement systems was a high risk time for piglet mortality, presumably due to accidental crushing by the sow. However, opening crates individually, when piglets reached seven days of age, resulted in lower post-opening piglet mortality relative to opening all crates once piglets reached an average age of seven days, particularly individual opening in the afternoon. Increased pre-opening disturbance in the farrowing house from opening crates individually may have increased the activity of the sows before crate opening, habituating sows and piglets to post-opening sow behaviour changes.

Acknowledgements

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Declaration of interest

No conflict of interest to declare.

Ethics statement

The project received ethical approval from Newcastle University.

Software and data repository resources

Data not available in an official repository.

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Table 1. Ethogram of sow behaviours recorded for four hours after crate opening, and during the same time period on the previous and subsequent days.

Sow behaviour	Description
Standing	Included standing, walking and kneeling.
Sitting	Dog-sitting, with rear and front hooves on the floor.
Ventral lying	Lying with neither shoulder on the ground.
Lateral lying	Lying with one shoulder on the ground.
Dangerous posture changes	Included all downward posture changes (stand-lie, sit-lie) and rolling (ventral-lateral, lateral-ventral).
Turning	Sow is standing and changes body direction by a minimum of 180º, usually from facing front-to-back or back-to-front of the pen.
Sniffing piglets	Sow moves snout towards one or more piglets.
Use of support	Sow leans on pen fixtures during stand-lie transition.
Riskiness of rolling	
Post-standing	A standing event has occurred since the previous rolling event.
Same side	No standing event has occurred, sow rolls onto the same side of the body as the previous roll.
Opposite side	No standing event has occurred, sow rolls onto the opposite side of the body as the previous roll.

Figure captions

Figure 1. Diagram of (a) temporary confinement pen, with (b) arrangement for 16 pens per converted room and (c) 20 pens per new cabin. Arrow indicates sow orientation when crate is closed.

Figure 2. Least square means (± s.e.) for piglet mortality. (a) Treatment effects during the post-opening ($P < 0.05$), late lactation ($P > 0.10$) and therefore after opening ($P = 0.052$) periods. (b) Housing type effects indicated between bars for each lactation period (n.s.($P > 0.05$), *($P < 0.05$), **($P < 0.01$)) and total lactation (◊($P < 0.05$)).

Figure 3. Least square means (± s.e.) for (a) frequency of sow dangerous posture changes and (b) total duration of sow postures. Day effects within each treatment between Before-During and Before-After are indicated on the latter day, whilst differences between During-After are indicated between days for each posture (*($P < 0.05$), **($P < 0.01$), ***($P < 0.001$)) and total postures (◊($P < 0.05$)). Treatment effects within each day are indicated with different letters ($P < 0.05$).

Figure 4. Least square means (± s.e.) for frequency of sow rolling by riskiness category. Day effects within each treatment between Before-During and Before-After are indicated on the latter treatment, whilst differences between During-After are indicated between treatments for each rolling category (*($P < 0.05$)) and total rolling frequency (◊($P < 0.05$)). Treatment effects within each day are indicated with different letters ($P < 0.05$).

Fig 1

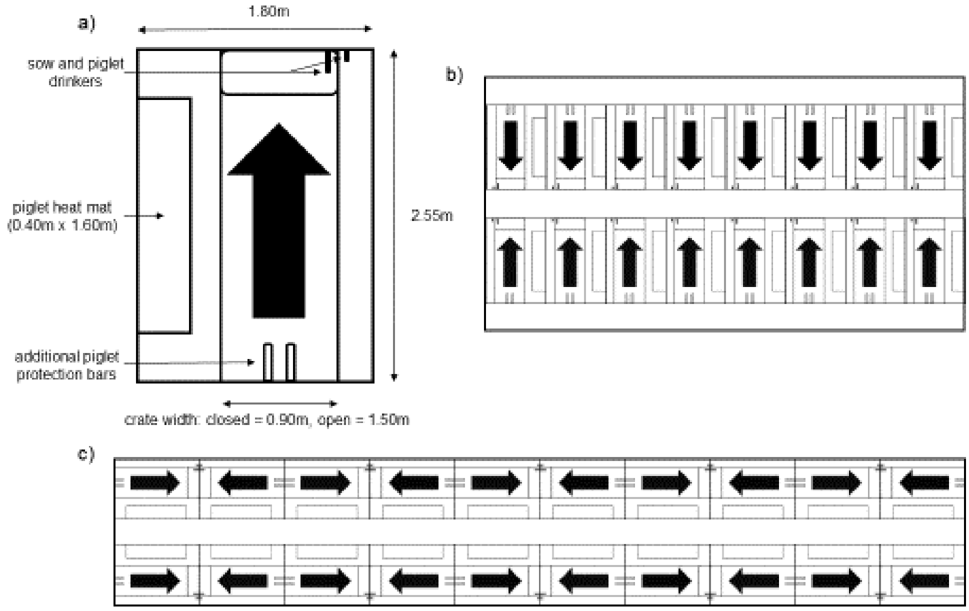
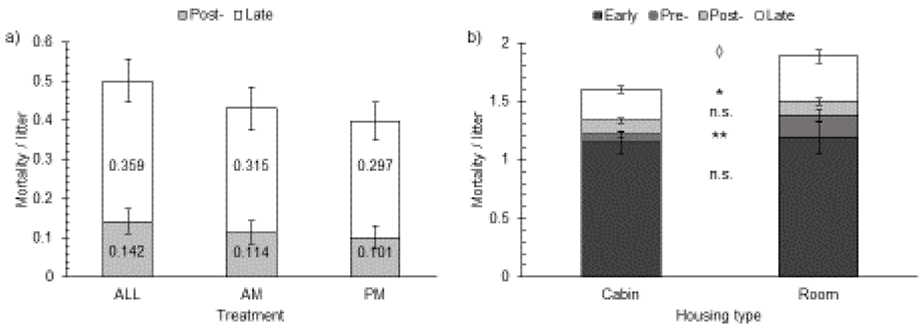

a)
1.80m
sow and piglet drinkers
piglet heat mat (0.40m x 1.60m)
additional piglet protection bars
2.55m
crate width: closed = 0.90m, open = 1.50m
b)
c)

Fig 2



Post-
Late
a)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Mortality / litter
0.359
0.142
0.315
0.114
0.297
0.101
ALL
AM
PM
Treatment
Early
Pre-
Post-
Late
b)
2
1.5
1
0.5
0
Mortality / litter
◊
*
n.s.
**
n.s.
Cabin
Room
Housing type

Fig 3

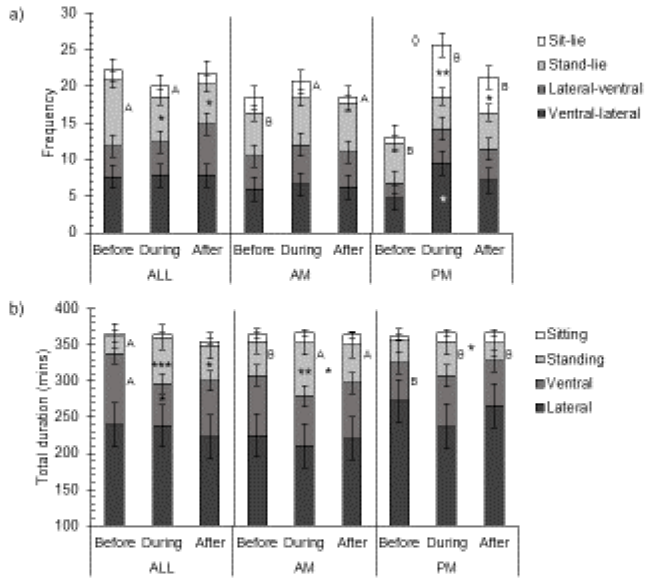
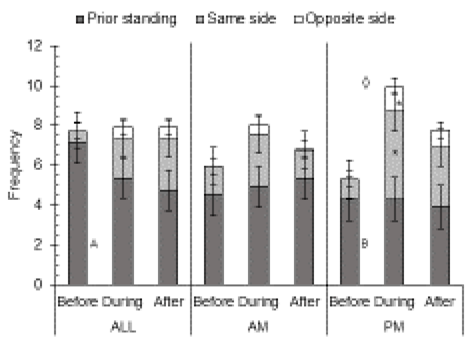

a)
Frequency
Before
During
After
ALL
AM
PM
Sit-lie
Stand-lie
Lateral-ventral
Ventral-lateral
b)
Total duration (mins)
Before
During
After
ALL
AM
PM
Sitting
Standing
Ventral
Lateral

Fig 4



Prior standing
Same side
Opposite side
Frequency
12
10
8
6
4
2
0
A
B
Before During After
Before During After
Before During After
ALL
AM
PM

Animal journal

Supplementary file

Temporary crate opening procedure affects immediate post-opening piglet mortality and sow behaviour

R.L. King[1], E.M. Baxter[2], S.M. Matheson[1] and S.A. Edwards[1]

Supplementary Methods

Figure S1. Temporary sow confinement pens in the cabin arrangement, illustrating crates in both the open (left) and closed (right) position (image courtesy of EM Baxter).

Figure S2. Temporary sow confinement pens in the room arrangement, illustrating crates in the open position, with the closest sows facing the rear of the pen (image courtesy of RL King).

Supplementary results

Supplementary Material S1. Results for average duration of sow posture changes.

Average duration of postures

Average bout duration of all postures by day and treatment are shown in Figure S2. Average duration of standing differed across days (*P* < 0.0001), being higher on the day of crate opening than the day before (*P* < 0.0001) or after (*P* < 0.001). Average duration of sitting was affected by treatment (*P* < 0.05), being higher for AM than both PM (*P* < 0.05) and ALL (*P* < 0.01). Average duration of ventral lying differed across days (*P* < 0.05), being higher on the day before than the day of crate opening (*P* = 0.01) and tending to be higher than the day after (*P* = 0.067).

Sow parity tended to affect the average duration of ventral lying (*P* < 0.069) and standing via a parity x day interaction (*P* = 0.059; Table S1). Average duration of ventral lying was lower for parity 1 sows (4.83mins ± 0.70) than parity 2-5 sows (6.28mins ± 0.61; *P* < 0.05) or parity 6+ sows (6.40mins ± 0.76; *P* = 0.058). Average duration of standing was increased on the day of crate opening than the day before or day after for parity 1 sows (before *P* < 0.0001; after *P* < 0.01) and parity 2-5 sows (before *P* < 0.001; after *P* < 0.01), but no different across days for parity 6+ sows. This meant that on the day of crate opening, average standing duration was lower for parity 6+ sows than both parity 1 sows (*P* < 0.01) and parity 2-5 sows (*P* = 0.057; Table S1).

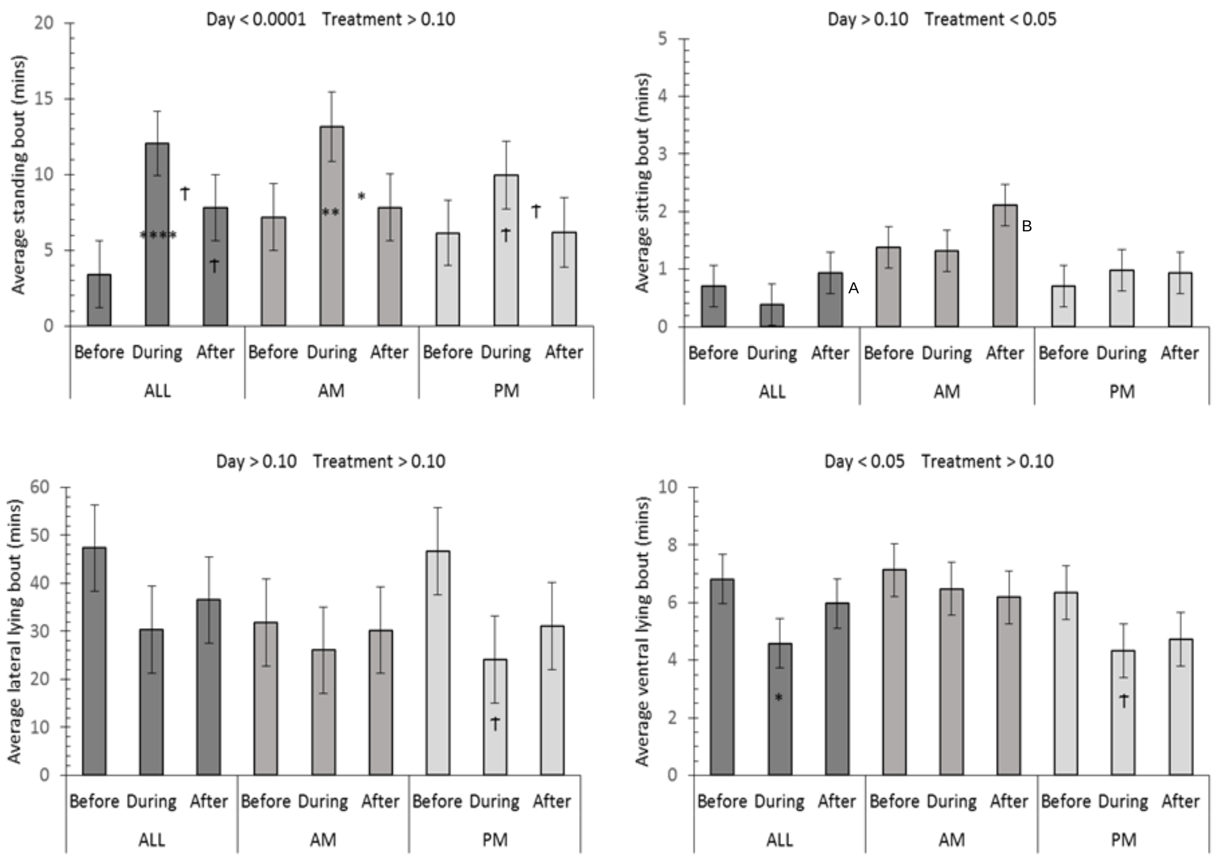


Figure S3. Least square means (± s.e.) for average duration of sow postures by day and crate opening treatment. Starting top left, clockwise: standing, sitting, ventral lying and lateral lying. Day effects within each treatment for Before-During and Before-After are indicated on the latter bar, with During-After differences indicated between bars (†($P < 0.10$), *($P < 0.05$), **($P < 0.01$), ****($P < 0.0001$)). Treatment effects within each day are indicated with different letters ($P < 0.05$).

Table S1. Least square means (± s.e.) of average sow standing bout duration (mins) by sow parity and day relative to crate opening.

Parity / Day	Before	During	After
1	4.35 ± 2.27^{a}	15.23 ± 2.37^{b}	8.10 ± 2.23^{a}
2-5	5.13 ± 2.01^{a}	11.98 ± 2.07^{b}	6.54 ± 1.96^{a}
6+	7.27 ± 2.23^{a}	7.99 ± 2.26^{a}	7.16 ± 2.25^{a}

^{a,b} Values within rows with different superscripts differ significantly ($P < 0.05$).