Rearing in female-only groups and dietary mineral supplementation improves sow welfare in the early parities, and lifetime performance

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Abstract

The lifetime performance of commercial sows relies on longevity, which is dependent on good health and reproductive performance. However there is a high rate of wastage of sows in the early parities which is influenced by the way they are managed and housed during rearing. This study investigated the carry-over effect of gilt rearing strategy on measures of welfare and performance. Eighty sows were reared using a 2 × 2 factorial design; rearing group composition (GC; female only (FEM) or mixed sex (MIX) from weaning), with or without supplementary minerals (MIN; CON = control diet; SUPP= control + Cu, Zn and Mn) from five weeks into the finisher stage. Once served, gilts were managed in a dynamic group gestation pen and fed a standard gestating sow diet. Locomotory ability was scored (0-5) and salivary cortisol measured 5 times during the 1st gestation, and human approach tests carried out at d108. Hooves were scored for injuries and legs for bursas at d70 of the 1st gestation, at 1st weaning, and at the 2nd farrowing. Sow behavior in the hoof scoring crate (movement, vocalization, handling ease) was also recorded. The numbers of piglets born alive and dead during the first 5 parities was recorded, as was the performance of the first litter to finish. Data were analyzed using general or generalized linear mixed models, as appropriate, using SAS (v 9.4). There was no effect (P > 0.05) of rearing treatment on locomotory ability, bursa score, the total number of piglets born or on offspring growth. However, there was an interaction between GC and MIN (P < 0.05) on salivary cortisol levels with MIX × SUPP sows having the highest levels. Total hoof scores and heel erosion scores were higher in sows reared in MIX groups (P < 0.01), and CON sows tended to have higher horizontal crack scores (P=0.06). Sows from MIX kicked more at weaning than FEM (P <0.05) and tended to be more fearful in the forced human approach (FHA) test (P = 0.1) where they are scored on their reaction to being approached. They also had more stillborn piglets across all 5 parities than FEM (P < 0.05). Overall, rearing replacement sows in FEM
groups and dietary mineral supplementation had minimal but beneficial effects on their subsequent welfare and performance.

Keywords: Gilt rearing, group composition, longevity, mineral supplementation, sow welfare
Introduction

Replacement gilts are the most valuable animals in the herd, as they are an investment with the potential to generate a profit (Stalder et al., 2003). Approximately 40 to 50% of sows are culled before their third or fourth parity (D'Allaire et al. 1987; Boyle et al. 1998; Schenck et al. 2008). However, they have not covered their replacement costs by this time (Stalder et al. 2003; Schenck et al. 2008). Rearing conditions for replacement gilts can affect development of the skeletal and other systems with subsequent effects on their health and performance in later life (Dewey 2006). Many studies show that the majority of skeletal development occurs in young animals, which indicates that the most important time for preventing muscular-skeletal issues is during early development (Loitz and Zernicke 1992; Umemura et al. 1995; Iwamoto et al. 2000). Nutrients and management factors affect issues of structural integrity (Nakano et al. 1987; Crenshaw 2006; Ytrehus et al. 2007; Crenshaw et al. 2013). Indeed Dijkhuizen et al. (1989) suggested that the greatest economic losses related to culling were due to locomotory problems.

Trace minerals Copper (Cu), Zinc (Zn) and Manganese (Mn) are important for maintaining fertility and claw integrity (Ballantine et al. 2002) and they also have roles in immune function (Tomlinson et al. 2004). Several studies demonstrate the benefits of supplementing sows with minerals during gestation (Anil et al. 2009; Ferket et al. 2009; Nair, 2011). There is less work investigating how supplementation during rearing could impact welfare, performance and longevity. Nevertheless, a gilt rearing diet should clearly be fortified with specific minerals to aid reproduction stimulation and to establish strong bones and legs for a lengthy breeding life (Close and Cole 2000).

Housing during rearing could also have long-term negative implications for sow welfare and longevity. In Ireland, the approximately 90% of farms rear their own replacement gilts, and these are often reared in the same pens as finisher pigs and kept in mixed-sex
groups up to slaughter age (Boyle and Bjorklund 2007; Quinn 2014; C. Carroll, personal communication). In Ireland pigs are not castrated, and as such replacement gilts are exposed to the high levels of aggressive and mounting behavior which entire male pigs perform (O’Driscoll et al. 2013; Teixeira and Boyle 2014). These behaviors increase the risk of injuries, such as limb and cartilage damage (Hartnett et al. 2019c), which are associated with lameness.

Osteochondrosis (OC) is a chronic degenerative joint disease (Dewey 2006; Nalon et al. 2013) which reduces sow longevity. However, OC lesions do not always produce clinical signs of pain and discomfort, as is the case in horses with severe pathological damage (Jeffcott 1996). There is already significant structural damage present in the joints of gilts at breeding age (Hartnett et al. 2019c). Although we did not find any association between the level of damage observed and the locomotory ability of these young animals, it is known that OC is associated with pain (Frantz 2006). Thus, it can be assumed that progressive damage to the joints could ultimately progress to lameness in later life, and potentially chronic stress associated with chronic pain (Kovacs et al., 2015). Prolonged stress and associated elevated cortisol levels can in turn disrupt reproduction in female pigs, which is a further risk factor for culling and reduced longevity (Turner et al. 2005).

A stressful prenatal environment can lead to permanent postnatal changes in offspring metabolism (Armitage et al. 2004; Wu et al. 2006; Hill et al. 2010). Both Haussmann et al. (2000) and Otten et al. (2000) indicated that prenatally stressed piglets from sows who were administered Adrenocorticotropic hormone (ACTH) exogenously tended to be lighter than piglets from gilts not exposed to ACTH. Prenatal stress is also associated with low birth weights in rodents and humans (Welberg and Seckl 2001). With regard to lameness specifically, Parada et al. (2017) found that this disorder in pregnant gilts had negative effects on their offspring’s growth and behavior.
The aim of this study was to investigate the carry-over effects of rearing replacement sows in female-only groups and of a trace mineral (Cu, Zn, Mn) supplemented diet, on aspects of their welfare in their early parities, and on their lifetime performance. We previously showed that these strategies had benefits for several aspects of gilt welfare up to breeding age (Hartnett et al., 2020), so we hypothesised that this would improve gilt welfare during the first pregnancy and have long-term benefits for longevity and reproductive performance. A secondary hypothesis was that offspring from gilts reared in female only groups and supplemented with dietary minerals would have higher birth weights, and improved performance from birth to finish.

**Materials and methods**

**Care and use of animals**

This study was carried out in the 200-sow unit at the Pig Development Department in Moorepark, Fermoy, Co. Cork, Ireland between December 2016 and August 2017. The experimental work was authorized by the Teagasc animal ethics committee (Approval no: TAEC136-2016) and licensed by the Health Products Regulatory Authority (License no: AE19132-P057).

**Experimental design**

Details of the experimental design including the treatments applied during the gilt rearing stage are outlined in Hartnett et al. (2020). In brief, a two by two factorial arrangement was applied to 288 gilts. The gilts were born from 52 sows which had been served using maternal line semen from Landrace sires (0153H Longo and 0096H Grande from Hermitage Pedigree Pigs Ltd., The Hermitage, Sion Road, Kilkenny, Ireland). They were born across four replicates, each replicate being three weeks apart.
The first factor in the experiment consisted of group composition, whereby half of the gilts were reared in female-only groups of 12 animals (FEM) from weaning onwards, and the other half were reared in mixed-sex groups (6 females and 6 males; MIX). The second factor consisted of mineral supplementation; half of each of the group composition treatments was fed a standard finisher diet until breeding age (CON) and the other half were fed the same diet, but with supplementary levels of Cu, Mn, and Zn applied (SUPP) from 17 weeks of age (5 weeks into the finisher stage) until breeding age. The control diet (CON) represented a typical standard finisher diet used on Irish commercial pig farms (50% barley, 33.5% wheat and 12% soybean oil). The mineral supplemented groups were fed the same diet, but supplemented with Availa Sow minerals (Zinpro Corp, Eden Prairie, MN, USA) which provided additional Cu, Zn, and Mn. Levels of CU, Zn and Mn for both diets, and the percentage supplied relative to the recommended amounts for gestating and lactating sows (NRC, 2012), can be seen in Table 1. All feed was in dry-pelleted form (3 mm).

Flooring in the weaner stage was plastic, and finisher stage was concrete. At slaughter age half of the pen mates (all males and 50% of the females) went to the abattoir. The remaining 182 gilts stayed in the same pens (6 females per pen) until breeding age when 102 of these gilts were sent for slaughter to allow for post-mortem limb analysis. The remaining 80 gilts were kept for breeding as replacements.

**Gestation management**

Twenty gilts from each rearing treatment group were kept for breeding (n = 80). A trained technician served the gilts twice using terminal line semen (Hermitage Genetics, Ireland) by artificial insemination, firstly at the onset of standing estrus and then 24 h later. Hereafter they are referred to as sows. Each batch of sows was served 3 weeks apart. After service, sows were housed in a dynamic group of approximately 120 sows. The building had fully slatted concrete passageways between insulated solid concrete floored
lying bays and the temperature was maintained at 18-20°C by mechanical ventilation. The sows had access to two electronic sow feeders (ESF; Schauer Feeding System, Prambachkirchen, Austria) that recognised each animal by a transponder tag programmed to her individual daily feed allowance. Sows had access to ad libitum water from single-bite drinkers in the ESFs and from five separate drinker bowls.

Approximately two weeks prior to their ‘due to farrow’ date pregnant sows were moved to a smaller pen for management purposes (ease of inspection and ease of movement to farrowing crates) for one week. The feed system, water access, heating and ventilation were the same as in the larger area described above. One week prior to farrowing sows were moved to the farrowing accommodation where they were penned in individual farrowing crates, in rooms housing either 7 or 14 sows. In the farrowing room the temperature was approximately 24°C at the time of farrowing thereafter, gradually reducing to 21°C by weaning age (day 27 postpartum). Heating was generated by hot water pipes (controlled via computer). In all houses there was artificial lighting (on from 0700-1700h). There was also natural lighting through the windows. Light to darkness cycle was approximately 12:12 (hrs) to allow for normal circadian rhythm.

Sows were provided with wooden chew posts in the gestation housing and a length of synthetic rope in the farrowing crate. Sows were inspected daily, and sick/injured animals were treated immediately; all antibiotic treatments were recorded.

**Live-weight and back-fat thickness**

All animals were weighed individually on day 7 and day 108 of gestation and at weaning using an electronic sow scales (EziWeigh 7i, O’Donovan Engineering, Co. Cork, Ireland). Back-fat thickness was measured on day 7, day 108 of gestation and on day of weaning using a Renco Lean Meter back-fat scanner on the P2 spot (last rib, 65 mm down the
dorsal middle line) on both sides of the body. Both recordings were averaged to provide a single back-fat measurement for each animal at each time point.

**Locomotory ability**

Sows were locomotion scored approximately every 3 weeks (22.8 ± 8.43 days) during the 1st gestation, and at weaning (day 27 postpartum) after their first litter. All sows had 5 inspections (days 52, 71, 92, 108 of gestation and weaning day 143). Locomotory ability was scored while the sows walked on solid concrete for a distance of approximately 30 meters, from the front, rear and side of the animal. All observations were carried out by one trained observer. Locomotion was assessed using the scoring system of Hartnett *et al.* (2019c), which was adapted from Calderon Diaz *et al.* (2013), and ranged from 0 (perfect locomotion) to 5 (unable to move).

**Salivary cortisol**

Saliva samples were collected on four occasions during gestation (on days 51, 71, 93 and 107) between 0930h and 1000h on the morning of collection. A fifth sample was also collected the morning after entering the farrowing house. Sows remained in the home pen for saliva sampling. They were encouraged to chew on a large cotton bud (Salivette, Sarstedt, Wexford, Ireland) until it was thoroughly moistened (approximately 30-60 seconds). The samples were placed in tubes and centrifuged for 15 min at 2500 x g, then stored at -20°C until analysis.

Saliva samples were analyzed using a commercially available cortisol assay kit (Salimetrics Europe Ltd., Suffolk, UK). Cortisol was detected at a minimum concentration of < 0.003 µg/dl. Inter-assay CV (n=24) = 4.69%. Intra-assay CV (n=794) = 7.68%.
Hoof lesion scoring and bursitis

Hoof lesion scoring was by visual inspection on day 70 and day 109 of gestation and on the day of weaning of the first litter. On day 109 of gestation the sows’ hooves were scored while they were lying down in the farrowing crates. For all other inspections the sows were raised 0.75 meters above the ground using a hydraulic chute (FeetFirst Sow Chute; Zinpro Performance Minerals, Eden Prairie, Minnesota, USA). The medial and lateral toes, medial and lateral dew claws, sole and heels of both hind feet were inspected, and severity of the following lesions scored; heel erosion, heel-sole separation, white line separation, dew claw length, dew claw cracks, toe length and vertical and horizontal toe cracks. The scoring system was a modified version of the FeetFirst claw lesion scoring guide from Zinpro Corporation. Details of the scoring system are described in Table 2.

While the animals were raised in the crate on day 70 of gestation and on the day of weaning, the hind legs were palpated, and bursa were scored on their size as follows (with 3 being the most severe): 0 = none, 1 = hazelnut, 2 = walnut, 3 = hens’ egg (Mouttotou et al., 1998). If more than one bursa was present each was scored separately.

Sow behavior

We monitored the behavior of sows in response to the hoof lesion scoring procedure in mid-gestation and at the first weaning. The ease with which the sow entered the crate, the amount of kicking she performed during examination, and whether or not she vocalized while in the crate, were scored according to the descriptions in Table 3, which were adapted from D’Eath et al (2009).

At day 106 of gestation, all gilts underwent a forced human approach (FHA) and forced human touch (FHT) test, as described by Kongsted, (2006). These were carried out in the home pen. For the FHA the researcher entered the pen, approached each gilt and squatted.
approximately 20 cm in front of her for 30 seconds. The behavior of the gilts was scored as per Table 4. Immediately after the FHA was complete, the FHT test commenced. The researcher attempted to touch the gilts neck and recorded the gilts reaction according to Table 4.

The final behavior observation was carried out when gilts were moved to the farrowing pens. As soon as the head reached the corner of the pen, a timer was started and the time it took the gilt to enter the farrowing crate was recorded.

**Sow performance at first farrowing**

Sows that became pregnant at first service were monitored at farrowing (day 114.6 ± 1.1 of gestation). Data collected included numbers of piglets born alive, still born and mummified. At birth, the weight and sex of each piglet was recorded, and all received an ear tag for identification. Piglets were weighed again at weaning age (27 days old). Cross fostering was kept to a minimum, and piglets were cross-fostered within treatment.

**Lifetime performance**

All performance data from the time of first service until the fifth farrowing were recorded and managed using PigChamp software (PigChamp Inc., Ames, Iowa, USA). Recorded data included dates of service, farrowing, weaning, and the number of piglets born alive and dead at each farrowing. At each parity sows that did not become pregnant after two services were excluded from the dataset, so as to mimic practices on a commercial pig unit. The reason for and age at culling was also recorded.
Offspring performance

At weaning, piglets were assigned to pens of 12 animals within treatment. Pigs were assigned to pens on the basis of sex and weight, and from approximately 4 sows per treatment combination (3.7 ± 1.1 sows contributing piglets/pen). As much as possible, equal numbers of male and female pigs were assigned to each pen (5.36 ± 1.03 males per pen across all treatments). The average weaning weight for pigs included in this part of the experiment was 7.36 ± 1.5kg. At weaning, there were a total of 9 pens of piglets from sows which had been reared in female-only pens with a standard finisher diet, and 8 pens each from sows reared on the other three treatment combinations. Weaner pens were 2.4 m × 2.6 m with a fully-slatted plastic floor. The temperature was maintained by automatic heating and negative pressure mechanical ventilation at 28°C in the weaner house immediately post-weaning. It was lowered by 2°C every 2 weeks thereafter.

After approximately 7 weeks (45.9 ± 2.6 days) in the weaner accommodation, pigs were moved in their groups to the finisher accommodation (concrete slatted floors 4 m × 2.4 m). In the finisher house the temperature was maintained at 20°C with the same ventilation system as in the weaner house, only without heating. All rooms were naturally illuminated by the windows. There was also artificial lighting (150 lux in weaner house and 130 lux in the finisher house) for 10-12 hours/day. Pigs remained in the finisher accommodation for approximately another 11 weeks (79.0 ± 0.6 days), before being sent to slaughter at a target weight of ~110 kg. Only pens that had at least 11 pigs remaining by the time of slaughter were retained in the analysis to control for the effect of space allowance on performance. Thus the analysis included 7 pens of pigs from both sows which had been reared in female-only pens with a standard finisher diet, from sows reared in mixed sex pens on the mineral supplemented diet, 8 pens from sows reared in female only pens on the mineral diet, and 6 pens from sows reared in mixed sex pens on the control diet.
Pigs were weighed (not fasted) at the move from the weaner house to the finisher house and on the day before slaughter. Throughout the production cycle, the pigs were fed ad libitum by a single-spaced wet-dry feeder with dry pelleted feed (one nipple drinker inside the feeder), with another nipple drinker providing water (i.e. two drinkers in the pen in total). Feed delivered to each pen in the weaner and finisher stage was recorded daily from the feed system and downloaded twice per week. These data were used to calculate the average daily feed intake (ADFI) at pen level. Combined with pen weights at weaning, the move to the finisher house and at the slaughter date, average daily gain (ADG) and feed conversion efficiency (FCE; ADFI / ADG) for both weaner and finisher stages were calculated.

**Statistical analysis**

Data were analyzed using the Statistical Analysis Systems statistical software package version 9.4 (SAS Institute Inc., 1989). The sow was used as the experimental unit for live-weight (LW), locomotory ability, salivary cortisol, hoof and bursa scores and performance data. Degrees of freedom were estimated using Kenwood-Rogers adjustment. Data are presented as LSmeans and standard errors. The Tukey-Kramer adjustment was used for multiple comparisons where least squares means (LSmeans) were determined. PROC UNIVARIATE was used initially for evaluating data distribution. For all models, fixed effects included group composition (MIX v’s FEM), dietary treatment (CON v’s SUPP) and the interaction, as well as replicate. Inspection day was included as a fixed effect for sow LW, back-fat, cortisol and hoof score analysis, and farrowing number for analysis of the number of piglets born alive. For cortisol analysis plate was included in the analysis as a random effect. Results were deemed statistically significant when α level was ≤ 0.05, and a tendency was considered when α level was between 0.05 and 0.1.

General linear mixed models (PROC MIXED) were used to analyze LW, back-fat cortisol and total hoof score data, and residuals were examined to verify normality and
homogeneity of variances. Generalized linear mixed models were used for locomotion, and bursitis data, individual hoof disorders, and the behavior tests (PROC GLIMMIX and PROC GENMOD).

For analysis of salivary cortisol, we carried out two analysis; 1) the four sampling points while in the group pen, and 2) cortisol level the morning after entering the farrowing crates. For the latter, cortisol level the morning before (i.e. the last sampling point in the group pen) was considered a covariate. We used a log transformation to normalise the data. Only sows that became pregnant on their first service were included in the analysis (n = 56).

The individual hoof disorders were also analyzed using generalized linear models (PROC GENMOD) as the data were ordinal, using a similar model to that used for locomotion scores. The maximum score present for each sow on each inspection day was the value included in analysis.

Locomotory behavior, and sow behavior variables related to use of the hoof inspection crate (ease of entry, kicks, vocalizations, and the sum of all measures) and the FHA and FHT were analyzed using generalized linear mixed models (PROC GLIMMIX). A multinomial distribution with a cumlogit link function was fitted. The models could not converge when data from each inspection day were included as repeated measures, and as such each inspection day was analyzed separately, and p-values adjusted post-hoc using a Bonferroni adjustment. The time it took to enter the farrowing crate was analyzed using a linear model (PROC MIXED).

The total number of piglets born, and the number born alive were analyzed across 5 parities using a mixed model as before. The number of piglets born dead was analyzed using a generalized mixed model (PROC GLIMMIX) with farrowing number as a random effect. Due to the low number of gilts from each treatment selected at breeding age (n = 20 per
treatment combination), the numbers surviving through each parity were not statistically analyzed, but raw data were summarized.

**Results**

**Live-weight and back-fat thickness**

There was no effect of either diet or group composition on sow LW or on back-fat thickness. Live-weight (P < 0.001) and back-fat thickness (P < 0.001) changed over time, yet there was no interaction between time and treatment. There was a significant difference between back-fat measurement at each time point (day 7 of gest, 16.24 ± 0.27 mm; day 108 of gestation, 17.31 ± 0.34 mm; weaning, 14.08 ± 0.37 mm; P < 0.001 for all comparisons).

**Locomotory ability**

There was no effect of either group composition or diet on locomotion scores of sows during pregnancy. The median locomotion score was 2 (IQR 1 – 2). In general, the sows showed good locomotion with only 13 incidences (n = 12 sows) of score 3 over the whole experimental period. No sow received a score of 4 or 5 throughout the experimental period.

**Salivary cortisol**

There was an interaction between group composition and diet (P < 0.05; Figure 1) on salivary cortisol levels with sows reared in mixed-sex groups and on a mineral supplemented diet having the highest cortisol levels during pregnancy. Although there was an effect of sample point on cortisol levels, there was no discernible pattern over time (P < 0.01). There was a tendency for SUPP sows to have higher cortisol levels than CON (P < 0.1).

On the first morning after moving from group housing to the farrowing house we found no effect of either group composition (back transformed means from the log: FEM, 0.175 µg/Dl vs. MIX, 0.171 µg/Dl) or diet (CON, 0.175 µg/Dl vs. SUPP, 0.171 µg/Dl) during rearing on salivary cortisol levels.
**Hoof lesion scores**

Total hoof scores were higher (i.e. worse) in the MIX (22.20 ± 0.61) sows than in the FEM (19.72 ± 0.59) sows (P < 0.005) across the study period. There was also an effect of inspection day, with hoof scores increasing over time (mid 1st gestation, 15.01 ± 0.53; farrowing 2nd gestation, 17.30 ± 0.49; weaning of 2nd farrowing, 30.58 ± 0.92; P < 0.001). When comparing treatment groups, we found that within the CON treatment there was a significant increase in total hoof scores in sows reared in MIX groups (P < 0.01; Figure 2). In the SUPP group we found no difference in hoof scores when comparing MIX and FEM sows (P > 0.6). Sows reared on the control diet tended to have higher horizontal crack scores than mineral supplemented sows (P < 0.1). Sows reared in FEM groups had lower heel erosion scores compared to sows reared in MIX groups (P < 0.05). There were no other effects of mineral supplementation or group composition on individual hoof disorders (Table 5).

**Bursitis**

There was no effect of group composition (P = 0.31) or mineral supplementation (P = 0.50) on bursitis scores (FEM, 2.03 ± 0.05; MIX, 1.96 ± 0.05; CON 2.02 ± 0.05; SUPP, 1.97 ± 0.05).

**Sow behavior**

There was no effect of either group composition or mineral supplementation on the sows’ movement score (P > 0.5 for all comparisons), or whether she vocalised or not (P > 0.12 for all comparisons), when being moved into and confined in the hoof scoring crate on any testing occasion. Neither did these factors have an effect on kicking at mid-gestation (P = 0.29; Figure 3). However, at weaning, although there was no effect of mineral supplementation on kicking score, MIX sows kicked more than FEM sows (P < 0.05; Figure
3). Likewise, on this test day, when all scores were added together, there was no effect of diet, but again, MIX sows tended to have higher scores than FEM sows (P = 0.1; Figure 4).

MIX gilts tended to have higher scores than FEM in the FHA test (P = 0.1; Figure 5). There was no effect on the FHT test (P > 0.45 for both the effect of diet and grouping strategy).

There was no effect of any factor on the time it took sows to walk into the farrowing crate. In general, this took 01:18 ± 00:08 (mm:ss) on average.

**Sow performance**

A percentage of the total number of sows that farrowed in each parity, and the total number of piglets born to sows in each of the treatments at each parity are provided in Tables 6 and 7 respectively. There was no effect of group composition or diet on the total number of pigs born alive for each sow, the number of piglets born alive per farrowing, or the total number of piglets born at each farrowing (Table 8). However, there was an effect of group composition on the numbers of stillborn piglets, with MIX gilts having the highest number of stillborn piglets across all five parities (P <0.05; Table 8).

**Offspring growth performance**

There was no effect of group composition or mineral supplementation during maternal rearing on offspring weight at any production stage, ADG (from birth to weaning, weaning stage and finisher stage), ADFI (weaning and finisher stage), or FCE (weaner and finisher stage). Data are presented in Table 9.

**Discussion**

There is evidence that improvements to the management and housing of a replacement gilt during rearing could help to improve sow longevity, primarily through reduced culling
for lameness (Dewey 2006) with associated benefits to animal health and welfare. As such, this study investigated the effect of two specific improvements to gilt nutrition and management (supplementation with minerals, and rearing in female-only groups) during the rearing period, having already demonstrated that these strategies had welfare benefits for gilts during the rearing period (Hartnett et al. 2019c). However, in the current study, we found there were few effects of either strategy on the sows welfare or performance in later life.

Overall, locomotion scores were good during the study period, with very few incidences of clinical lameness (sows scoring 3 or greater) and no incidences of scores 4 and 5. Even though there was little lameness in the animals during rearing (Hartnett et al. 2019c), we expected that differences between the treatments may have manifested later in life, due to the cumulative effects of the damage which occurred during rearing exacerbated by the weight demand of pregnancy on the sow. The two most commonly used breeds of sow in Ireland are the Landrace and Large White. Of these, the Landrace is hypothesized to be more susceptible to osteochondrosis, and leg weakness in general, than the Large White (Jorgensen and Andersen, 2000), which is why we selected this breed for the study. Thus it is promising that locomotion scores remained so low, and may have been lower yet if Large White sows were used. Nevertheless, the numbers used in the study were small, and it has to be noted that the gilts we selected for breeding were considered the healthiest of the pool of 182 which were available (no obvious health issues or locomotory problems, closest to the average weight of the group). All of the 102 gilts which were send to slaughter at breeding age had visually detectable osteochondrosis lesions when we examined their limbs (Hartnett et al., 2019a). As such, in a commercial situation, it is possible that there could be a greater likelihood of animals staying in the sow herd which subsequently develop lameness.
Although the median lameness score increased from 1 during rearing to 2 during pregnancy, which demonstrates that there was a slight impairment to locomotion overall, relative to the rearing period, the locomotory ability of the animals in the different rearing treatments did not diverge. The increase during gestation may simply have been due to added weight and growth during gestation, as well as potentially to the accumulation of injuries.

Hoof lesion scores in mid gestation were considerably higher compared to the scores recorded in the same gilts during rearing (Hartnett et al., 2020). Furthermore, they continued to increase until the last inspection, when sows farrowed for the second time. The increase in hoof scores over time was likely due to general wear and tear with age, as the hooves must support more weight as bodyweight and size increases. This is further complicated by housing on fully slatted floors, which can result in injuries due to claws becoming caught or trapped in the slats (Gjein and Larssen 1995a; Pluym et al. 2011). Hoof lesions can be associated with pain and irritation as the lesions on the surface of the hoof affect sensitive tissues, and secondary infections may occur as a result (Zoric et al. 2004). Nevertheless, none of the hoof disorders we observed were severe, and this could explain why no differences in locomotion score were observed. In line with findings on the same animals during rearing (Hartnett et al., 2020) total hoof lesion scores were higher in the sows reared in mixed-sex groups compared with sows reared in female-only groups. Thus, the claw horn damage resulting from more activity (mounting, aggression, and play) on the concrete slatted floors during rearing persisted (Gjein and Larssen 1995a; Pluym et al. 2011; Quinn et al. 2015). This is not surprising as concrete floors offer little opportunity for claw horn lesions to resolve (Heinonen et al. 2013b), and the animals were managed on fully slatted concrete floors throughout their lives.
When considering only sows that were reared on the control diet, we found that those in mixed-sex groups had higher total hoof lesion scores than those reared in the female-only groups, whereas this was not the case for sows reared on the mineral supplemented diet. This suggests that the mineral supplemented diet had a long-term protective effect on hoof health. Thus, if space or other constraints do not permit separate sex rearing, supplementation with the minerals used in the current study could have long term benefits for hoof health in sows. In other studies the heel and horn wall region were the most affected areas of the hoof (Gjein and Larssen 1995a; Kirk et al. 2005; Anil et al. 2007; Pluym et al. 2011) and indeed these were the two regions of the claw where we saw the greatest treatment effect. Sows reared on the control diet tended to have higher horizontal crack scores than mineral supplemented sows, and sows reared in female-only groups had lower heel erosion scores compared to sows reared in mixed-sex groups. Studies with pregnant sows found that the addition of the trace minerals similar to the ones used in the current study, improved claw health (Nair, 2011) and reduced the prevalence of lameness and leg abnormalities (Ferket et al. 2009). Nair (2011) found that the addition of trace minerals Cu, Zn and Mn to the diet of the breeding sow resulted in the reduction of heal erosion and white line lesions. However, similar to Quinn et al. (2015) we found that overall there was a low prevalence of severe lesions and a high prevalence of mild lesions. Mild lesions do not appear to influence locomotory ability (Gjein and Larssen 1995b; Anil et al. 2007; Quinn et al. 2015) which could explain the lack of effect of treatment on the locomotion scores in the current study.

Surprisingly, we found that sows reared in supplemented groups tended to have higher cortisol levels than those reared on a standard finisher diet. Nevertheless, it is important to note that the difference was only a tendency, and thus the result must be interpreted with
caution. In fact, the difference was driven by sows which were reared in mixed sex groups having higher cortisol levels when they were supplemented with minerals than when they were reared on the control diet; there was no effect of supplementation for gilts reared in the female only groups. This result is in contrast to what we expected, and it is not clear why when supplemented the mixed sex sows had such high levels; levels were also numerically much higher than sows which had been reared on the control diet, using either grouping strategy. However, cortisol levels are affected by more than stress, and factors such as exercise level, excitement etc. can also increase secretion levels. Moreover, although statistically different, levels detected were within the normal range for salivary cortisol levels of pregnant gilts (e.g. Rooney et al., 2019). When measuring the effect of chronic stress (e.g. due to lameness, social stress etc.) patterns of cortisol secretion throughout the day, or the ability of the animal to increase cortisol secretion in response to a stressor may be more informative than simply sampling the animal at one sampling point a day. A blunted circadian pattern of secretion, or inability to mount a cortisol response, are considered more reliable indicators of chronic stress than basal cortisol levels (Munsterhjelm et al., 2010).

We decided to record handling ease, incidence of kicking and vocalizing as we hypothesized they would provide simple objective measurement of a lack of ‘calmness’ or in other words, an elevated level of re-activity, and similar measures have previously been used to assess pig temperament (D’Eath et al., 2009). Even though we did not see differences in locomotory ability, gilts reared in mixed-sex groups kicked more during confinement in the hoof crate, and performed more avoidance behavior of a human, than gilts reared in female only groups. These gilts may have been experiencing more limb discomfort in general. Hartnett et al. (2019) found that gilts reared with males had more cartilage damage at
breeding age, particularly on the humeral condyle, than those reared in female only groups, which aligns with our finding that sows reared with males had more hoof damage during gestation and into the 2nd parity. The sows in the current paper represent the gilts in the study by Hartnett et al. (2019) at an older age so it is possible that any damage sustained to cartilage deteriorated faster in the gilts reared with male pigs than those reared with females. Cartilage damage is considered progressive and healing response is limited (Lin et al., 2017). It is possible that any discomfort due to cartilage degeneration could have caused pigs to have a heightened response to the unusual sensation of being raised in the hoof examination crate, and their limbs and hooves being handled. Indeed Mohling et al. (2014) found that the mechanical nociceptive threshold was reduced even in the cannon area of the limb, after injection of Amphotericin B into the interphalangeal joint space. This is not to say that the gilts reared with males in the current experiment experienced pain while having their hooves examined, but rather they may have been more reactive to an unexpected experience of pressure or release on the limbs.

With regard to the increased avoidance response by MIX sows to the FHA test, again, this could be due to a slightly reduced ability to tolerate a novel experience. Rearing conditions have lifelong effects on animal behavior (Beattie et al., 1995) and stress responses (Olsson et al., 1999), and the gilts reared with males were exposed to much higher levels of activity, aggressive behavior, and mounting, for the first 7 months of their lives, relative to gilts in female only groups (Hartnett et al., 2020). We were unable to source information in the literature regarding the long-term behavioral effect on gilts of rearing with un-castrated male pigs. However, Olsson et al. (1999) found that rearing conditions up to 10 weeks of age
can affect the behavioral response to challenges when gilts were aged between 9 and 11 months old.

It is unfortunate that the sample size was so low that statistical analysis of the data pertaining to sow longevity and total piglet output at each farrowing would not yield useful results which would be robust enough to be transferrable to industry. Nevertheless, we can see from the raw data that sows reared with the optimal diet (i.e. the mineral supplement) numerically stayed in the herd longer than those on the control diet. With regard to the grouping strategies, sows reared with males seemed to remain longer. Thus numerically gilts reared with the mineral supplement produced more piglets ‘born alive’ over five parities than those on the control diet, whereas gilts reared with males produced numerically more ‘born alive’ piglets than those in the female-only groups. At the same time, gilts reared with males had significantly more piglets born dead over the five parities. Although these data are preliminary and more animals are needed to make a meaningful comparison of sow longevity having been reared in these treatments, we feel that they may be useful as pilot data for researchers planning future studies and generating hypothesis, and as such a useful addition to the literature. Moreover, it would also be interesting to investigate further the effect of rearing with males on time to first estrus, and whether this could enhance reproductive performance.

As we have confirmed that both hoof health and cartilage condition (Hartnett et al., 2019) was negatively impacted by both rearing with males and the standard finisher diet, we expected that sows from these treatments would have experienced pain and stress during gestation, even if there were no overt signs of lameness. There is evidence in the literature that maternal stress during pregnancy can affect the developing piglets and negatively affect
their growth. For instance, social stress in gestating pigs can cause reduced offspring weight gain post-weaning (Rutherford et al. 2012). However, we found no effect of either treatment on offspring performance either pre or post weaning. This was the case even though we found higher salivary cortisol levels in gilts reared with males and provided with the mineral supplement. Thus it appears that neither rearing strategy had a long term effect on offspring growth or efficiency.

Physical growth is not the only trait which can be affected by exposure to stress in-utero. In a sister study to the current one, we carried out open field tests on a subsample of the piglets born to the sows used in the current study, and we found a range of behavioral differences in offspring born to gilts from the different treatment groups in the current study' (Hartnett et al. 2019a). Piglets from gilts reared with males screamed (i.e. sudden, loud vocalization) more in an open arena test than those from the female-only groups, and piglets from gilts supplemented with the minerals explored more, stood still less, and grunted less, than those on the control diet. Thus, although there was no effect on physical performance, there is yet the possibility that piglets were behaviorally affected by maternal rearing (Hartnett et al. 2019a).

Conclusions

During gestation, hoof health was poorest in sows fed a standard finisher diet without supplementation and reared in mixed-sex pens compared to all other treatment combinations; therefore, if space is limited, supplementary minerals may help ameliorate some of the negative effects of rearing gilts with entire male pigs. However, supplementing gilts with minerals during rearing resulted in minor albeit positive effects on the severity of hoof cracks during pregnancy. Overall, rearing gilts in female-only groups had minor, but beneficial
effects on their welfare subsequent to the rearing period. The addition of supplementary minerals to the diet was also beneficial for hoof health when gilts were reared in mixed-sex groups.
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**Figure 1.** Salivary cortisol levels during gestation in sows reared either in female-only (FEM) or mixed-sex (MIX) pens, and fed a control finisher diet (CON) or the same diet supplemented with Cu, Mn and Zn (SUPP). Cortisol levels were log transformed prior to analysis. Data are presented using back transformed means and standard errors.

**Figure 2.** Total hoof scores in sows showing an effect of group composition (FEM, female-only; MIX, mixed-sex) when reared on the CON diet (control diet) compared to no effect of group composition when reared on the SUPP diet (mineral supplemented diet). Eight different aspects of hoof health (heel erosion, heel-sole separation, white line separation, dew claw length, dew claw cracks, toe length and vertical and horizontal toe cracks) were scored from 0 (perfect) to 3 or 4 (extreme damage), and the scores summed to provide a total score. Thus the higher the score, the more damage to the hoof.

**Figure 3.** The percentage of gilts which either did not kick (Score 0) or did kick (Score 1) when they were raised above the ground in the hoof scoring chute and their hooves were handled for scoring.

**Figure 4.** The percentage of gilts which fell into each category when the scores from all three reactions to the hoof crate observations were summed. At weaning, more sows which had been reared in mixed-sex groups tended to have higher scores (i.e. worse, indicating that they were more fearful) than sows which had been reared in single sex groups.
Figure 5. The proportion of gilts in each scoring category for the forced human approach (FHA) test. A higher score indicates a greater level of fearfulness. Gilts had been reared in either female-only (Female), or mixed-sex (Mixed) pens from weaning age (28 days) until finisher age (140 days of age).
Table 1. Mineral inclusion rates in the diets of control (fed to all pigs) and supplemented (SUPP; from day 117.5 ± 0.6 of age) finisher pigs. Values are expressed as mg/kg (i.e. parts per million, and as a % of NRC recommendations for gestating and lactating sows.

|       | NRC (mg/kg)<sup>1</sup> | Control (mg/kg) | SUPP (mg/kg) | Control %<sup>2</sup> | SUPP %<sup>2</sup> |
|-------|-------------------------|-----------------|--------------|-----------------------|---------------------|
| Mn    | 25                      | 25.1            | 51.45        | 101%                  | 206%                |
| Zn    | 100                     | 55.6            | 122.29       | 56%                   | 122%                |
| Cu    | 10                      | 4.5             | 17.89        | 45%                   | 179%                |

<sup>1</sup> NRC gestating and lactating sow requirements.

<sup>2</sup> Values in the control and mineral diet as a percentage of the NRC recommendations.
Table 2. Claw lesion scoring system (Zinpro Corporation, USA).

| Scores | Toe length | Dew claw length | Dew claw injuries | Heel overgrowth and erosion | Heel sole crack | White line damage | Horizontal wall crack | Vertical wall crack |
|--------|------------|----------------|------------------|----------------------------|----------------|------------------|----------------------|---------------------|
| 0      | Normal     | Normal          | Normal            | Normal                     | Normal         | Normal            | Normal          | Normal             |
| 1      | ≥1 toes slightly longer than normal: | Slightly longer than normal | Short crack or cracks in the skin of the heel | Separation at the junction has just begun; length of separation < 0.5 cm | Shallow separation | Hemorrhage evident, short/horizontal crack in toe | Normal | Normal |
|        | Difference detected only when sole is pressed flat | | | | | | | |
| 2      | ≥1 toes moderately longer than normal: | Significantly longer than normal | Long but shallow crack or overgrowth | Slight separation | Long separation | Long but shallow horizontal crack in wall | Normal | Normal |
|        | difference obvious without flattening sole | | | | | | | |
| 3      | ≥1 claws much longer than normal | Multiple or deep crack or cracks with separation at deep tissue | Numerous | Long | Long and deep | Multiple or deep crack or cracks in the | Normal | Normal |
| and/or the toes are | normal and/or | cracks in dew claw and | obvious overgrowth and erosion | the juncture, separation which is deeper than score 2 | horizontal crack or cracks in toe wall along white line wall |
|---------------------|--------------|------------------------|-------------------------------|-----------------------------------------------|--------------------------------------------------|
| torn and/ or partially | the claws are torn | or/partially or completely missing | | | |
| or completely missing | | | | | |

| 4 | ≥1 toes significantly longer than normal | Large amount of erosion and overgrowth with cracks | Long and deep separation at the juncture | | |

| 38 |
Table 3. Scoring system for the reaction of sows to entering and being confined in the hoof scoring crate. Adapted from D’Eath et al. (2009).

| Aspect of behavior   | Score | Description                                           |
|----------------------|-------|-------------------------------------------------------|
| Movement into crate  | 0     | Pig walks voluntarily into crate                      |
|                      | 1     | Short, single push needed to get pig into crate       |
|                      | 2     | Constant pushing required                             |
|                      | 3     | Total refusal by the pig                              |
| Kicking              | 0     | None – pig relaxed                                    |
|                      | 1     | Intermittent kicking                                  |
|                      | 2     | Continuous kicking                                    |
| Vocalizations        | 0     | No vocalizations while confined                       |
|                      | 1     | The sow vocalised at least once while confined        |
Table 4. Scoring system for the forced human approach (FHA) and forced human touch test (FHT) which gilts underwent on days 106 and 107 of gestation.

| Test | Score | Definition |
|------|-------|------------|
| FHA  | 1     | Fled when human was >1m from her |
|      | 2     | Gilt turned head away, or moved a few steps from human, once the human got into the test position. The gilt stayed in that area or continued what she was doing for the remainder of the test period. |
|      | 3     | Gilt turned head away, or moved a few steps but initiated contact with the human with in the test period. |
|      | 4     | Gilt did not react to the human approach. Remained in same position or continued with its own activity. |
|      | 5     | Did not react to human approach but initiated contact with the human. |
|      | 6     | Approached the human and initiated physical contact. |
| FHT  | 1     | Pig fled before human made contact, with or without squealing, stood still holding head stiff while keeping eyes fixed. |
|      | 2     | Pig walked away without vocalising |
|      | 3     | Pig stood calmly, approached the human. |
Table 5. Individual hoof disorders of gestating sows reared in either mixed-sex (MIX) or female-only (FEM) groups and on a standard finisher diet (CON) or on a CON diet supplemented with minerals (SUPP). Data are provided as median and interquartile ranges. There were no interactive effects between diet and group composition.

| Diet                      | CON     | SUPP    | P-value | Group composition | FEM     | MIX     | P-value |
|---------------------------|---------|---------|---------|-------------------|---------|---------|---------|
| Heel erosion\(^2\)        | 1 (1-2) | 2 (1-2) | 0.92    |                   | 2 (1-2) | 2 (2-3) | 0.05    |
| Heel sole separation\(^2\)| 1 (0-2) | 1 (0-2) | 0.97    |                   | 1 (0-2) | 1 (0-2) | 0.93    |
| White line separation\(^2\)| 2 (1-3) | 2 (1-2) | 0.17    |                   | 2 (1-2) | 2 (1-2) | 0.43    |
| Vertical cracks\(^2\)     | 1 (0-1) | 0 (0-1) | 0.25    |                   | 0 (0-1) | 1 (0-1) | 0.15    |
| Horizontal cracks\(^2\)  | 0 (0-1) | 0 (0-0) | 0.06    |                   | 0 (0-0) | 0 (0-0) | 1.00    |
| Dew claw length\(^2\)     | 1 (1-2) | 1 (1-2) | 0.41    |                   | 1 (1-2) | 1 (1-2) | 0.54    |
| Dew claw cracks\(^2\)     | 1 (0-1) | 1 (0-1) | 0.83    |                   | 0 (0-1) | 1 (0-2) | 0.15    |
| Toe length\(^2\)          | 1 (1-1) | 1 (1-1) | NS      |                   | 1 (1-1) | 1 (1-1) | NS      |
Table 6. The percentage of breeding females which remained in the herd at each parity. A total of 40 breeding females were selected for service within each individual treatment at breeding age. Sows which were culled, did not become pregnant after being served twice at any parity, or failed to return to estrus after farrowing she was removed from the data set.

| Parity | Control | Mineral | Female | Mixed |
|--------|---------|---------|--------|-------|
| 1      | 78%     | 85%     | 83%    | 80%   |
| 2      | 58%     | 65%     | 55%    | 68%   |
| 3      | 40%     | 48%     | 43%    | 45%   |
| 4      | 35%     | 40%     | 35%    | 40%   |
| 5      | 33%     | 33%     | 30%    | 35%   |
Table 7. The total number of piglets born alive (BA) to breeding females within each treatment at each parity. Data are presented as raw figures without statistical analysis. All gilts which reached each parity are included in the summary, to provide a total per ‘herd’.

| Parity     | Control Total | Control Per sow | Mineral Total | Mineral Per sow | Female Total | Female Per sow | Mixed Total | Mixed Per sow |
|------------|---------------|-----------------|---------------|-----------------|--------------|----------------|-------------|---------------|
| Parity 1   | 368           | 11.9            | 391           | 11.5            | 394          | 11.9           | 365         | 11.4          |
| Parity 2   | 292           | 12.7            | 362           | 13.9            | 285          | 13.0           | 369         | 13.7          |
| Parity 3   | 216           | 13.5            | 281           | 14.8            | 248          | 14.6           | 249         | 13.8          |
| Parity 4   | 210           | 15.0            | 243           | 15.2            | 214          | 15.3           | 239         | 14.9          |
| Parity 5   | 207           | 15.9            | 206           | 15.8            | 186          | 15.5           | 227         | 16.2          |
| All parities | 1293         | 1483            | 1327          | 1449            |              |                |             |               |
**Table 8.** Sow performance data from breeding females showing lifetime performance over 5 parities and also average performance by farrowing. There was no interaction between diet and group composition for any measure.

| Diet      | Group composition |          |          |          |          |          |          |
|-----------|-------------------|----------|----------|----------|----------|----------|----------|
| Control   | Mineral           | P value  | Female   | Mixed    | P value  |
| Lifetime BA\(^1\) | 34.34±5.03         | 40.53±5.03 | 0.39     | 35.06±5.03 | 39.81±5.03 | 0.51     |
| Stillborn\(^2\) | 78                 | 103      | 0.45     | 62       | 119      | 0.02     |
| By farrowing | Born alive      | 13.81±0.39 | 14.01±0.38 | 0.71     | 14.01±0.39 | 13.80±0.38 | 0.69     |
|          | Total born        | 14.98±0.40 | 15.60±0.39 | 0.26     | 15.14±0.40 | 15.44±0.39 | 0.58     |

\(^1\) The average number of piglets born alive (BA) to a sow within each treatment. Data were collected over 5 parities.

\(^2\) Data represent the total number of stillborn piglets from all sows within each treatment, over 5 parities. Data were analyzed on a per sow basis, including parity as a random effect, to generate p-values.
Table 9. Pre and post-weaning growth performance of the offspring of sows reared in either female-only (FEM) or mixed-sex (MIX) groups and on a standard finisher diet (CON) or on a CON diet supplemented with minerals (SUPP).

| Diet     | Group Composition | CON | SUPP | P-value | FEM | MIX | P-value |
|----------|-------------------|-----|------|---------|-----|-----|---------|
| Weight (kg)* |                  |     |      |         |     |     |         |
| Total born   |                  | 1.19 ± 0.06 | 1.20 ± 0.06 | 0.97 | 1.19 ± 0.06 | 1.20 ± 0.06 | 0.93 |
| Live born    |                  | 1.35 ± 0.05 | 1.40 ± 0.04 | 0.43 | 1.36 ± 0.04 | 1.38 ± 0.05 | 0.75 |
| ADG         |                  | 0.21 ± 0.01 | 0.22 ± 0.01 | 0.59 | 0.22 ± 0.01 | 0.22 ± 0.01 | 0.93 |
| Weaning     |                  | 7.49 ± 0.25 | 7.30 ± 0.23 | 0.59 | 7.22 ± 0.21 | 7.57 ± 0.25 | 0.29 |
| ADG (kg/day)* |                |     |      |         |     |     |         |
| Weaner      |                  | 0.57 ± 0.02 | 0.58 ± 0.01 | 0.95 | 0.58 ± 0.01 | 0.57 ± 0.02 | 0.97 |
| Finisher    |                  | 0.90 ± 0.02 | 0.91 ± 0.01 | 0.95 | 0.90 ± 0.01 | 0.92 ± 0.02 | 0.87 |
| ADFI (Kg/day)* |              |     |      |         |     |     |         |
| Weaner      |                  | 0.86 ± 0.03 | 0.92 ± 0.03 | 0.54 | 0.90 ± 0.03 | 0.88 ± 0.03 | 0.93 |
| Finisher    |                  | 1.99 ± 0.03 | 2.02 ± 0.03 | 0.92 | 2.00 ± 0.03 | 2.01 ± 0.03 | 0.99 |
| FCE (g/g)   |                  |     |      |         |     |     |         |
| Phase   | Value 1 | Value 2 | Calculation | Value 3 | Value 4 | Result |
|---------|---------|---------|-------------|---------|---------|--------|
| Weaner  | 1.51 ± 0.03 | 1.57 ± 0.03 | 0.54 | 1.55 ± 0.02 | 1.53 ± 0.03 | 0.94 |
| Finisher| 2.22 ± 0.03 | 2.22 ± 0.02 | 0.99 | 2.22 ± 0.02 | 2.21 ± 0.03 | 0.99 |

*Data are provided as Least Squares means and standard errors.*
Figure 4

![Bar chart showing data comparison between different categories.](https://academic.oup.com/tas/advance-article-doi/10.1093/tas/txaa176/5909380)
