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**Artificial rearing affects piglets pre-weaning behaviour, welfare and growth performance**

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**Abstract**

One strategy adopted on farms to deal with managing large litters involves removing piglets from their mothers at seven days old to be reared in specialised accommodation with milk replacer. Effects on piglet behaviour, growth and some aspects of welfare were evaluated in this study by comparing 10 pairs of two litters (one sow-reared: SR, one artificially-reared: AR) selected at seven days-old at a similar weight. Piglet behaviour was recorded for 20 min following transfer of AR piglets to the artificial-rearing enclosure (D0) and for 20 min hourly between 09:00h and 17:00h (8h) on D5 and D12. Hourly 5 min live observations were also undertaken. Qualitative Behavioural Assessment (QBA) was conducted on D14 to evaluate piglets' emotional state. Survival and illness events were recorded until weaning. On D0, D1, D8 and D15 piglets were weighed and scored for tear staining, dirtiness of the face and severity of lesions on the snout, limbs, ear and tail. Survival and illness rates, as well as the rates of behaviours/min were analysed using GLMMs. Weights and QBA scores were analysed using GLM. Lesions, tear staining and dirtiness scores were averaged per litter and analysed using GLM. When AR piglets were transferred to the artificial-rearing enclosure, their behaviour was not different to SR piglets. Over the two observation days, AR piglets performed more belly-nosing ($F_{1,76.53}$ = 42.25; P<0.001), nursing-related displacements ($F_{1,79}$ = 19.32, P<0.001), visits to the milk cup (compared to nursing bouts; $F_{1,73.8}$ = 38.42, P<0.001), and oral manipulation of littermates' ears ($F_{1,91.95}$ = 12.79, P<0.001) and tails ($F_{1,58.54}$ = 15.63, P<0.001) than SR piglets. However, SR piglets played alone ($F_{1,88.99}$ = 8.29, P<0.005) and explored their environment ($F_{1,99.42}$ = 4.52, P<0.05) more frequently than AR piglets. The QBA scores indicated a lower emotional state in AR piglets ($t_{25.1}$ = -3.25, P<0.05). Survival rate and overall illness rate of piglets were similar between the treatments. AR piglets experienced a growth check following their transfer to the artificial-rearing enclosure and remained lighter than SR piglets through to weaning (6.53 ± 0.139 kg vs. 7.97 ± 0.168 kg, $t_{256}$ = 9.79, P<0.001). Overall, snout lesion scores were not different between the treatments, but AR piglets had lower limb ($F_{1,10.1}$ = 5.89, P<0.05) and ear ($F_{1,14.5}$ = 24.89, P<0.001) lesion scores and higher tail lesion scores ($F_{1,34.5}$ = 15.54, P<0.001). AR piglets were dirtier ($F_{1,17.4}$ =

23.38, P<0.001) but had lower tear staining scores ($F_{1,19.1}$ = 68.40, P<0.001) than SR piglets. In conclusion, artificial rearing impaired piglets' behaviour, welfare and growth.

**Keywords**

Piglets; Artificial rearing; Welfare; Performance, Behaviour

## 1. Introduction

Artificial-rearing systems involve removing piglets from their mother at two to 14 days of age (Baxter et al., 2013) and transferring them to specialised enclosures which are typically located either in a separate room or above the sow's farrowing crate (e.g. Rescue Decks®). These enclosures provide the piglets with warmth, milk replacer and solid food (Baxter et al., 2013), and remove the need for nurse sows. They could be considered as an "intervention system" to rescue piglets that cannot be reared by the sow and they are becoming more commonly used as genetic selection for large litters results in more piglets than available teats, thus increasing the risk of piglet mortality. However there are potentially contentious issues with these systems particularly relating to the definition of weaning. If weaning is considered the removal of the piglet from its mother and its mother's milk then artificial rearing is early weaning. However if weaning is considered the removal of milk then artificial rearing systems would consider full weaning to occur when liquid feeding (milk replacer) is stopped and piglets are moved to weaner facilities and fed solid food (at approximately 28 days of age). Regardless of this discussion, it is clear that there is limited scientific evidence about the welfare outcomes of artificial rearing withmost studies focusing on piglet health and performance, with some (Cabrera et al., 2010; van Beirendonck et al., 2015), but not all (De Vos et al., 2014) claiming increases in pre-weaning growth. Reduction in pre-weaning growth could be due to a short-term malfunctioning of the gut (De Vos et al., 2014; Huygelen et al., 2012), although De Vos et al. (2014) did report long-term improvements to gut maturation. Where heavier weaning weights were recorded in artificially-reared piglets compared to sow-reared piglets, they were found to be unsustainable post-weaning (Cabrera et al., 2010; van Beirendonck et al., 2015) and artificially-reared piglets had lower carcass quality at slaughter (i.e. lower loin depth and lean percentage) (Cabrera et al., 2010). Benefits for growth of artificially-reared piglets are likely to come towards the end of lactation, as they have access to ad libitum milk replacer whereas sow-reared piglets experience a decrease in sows milking capacity (Quesnel et al., 2012). Nevertheless, results tend to differ slightly among studies. This could be due to a number of factors, including differences in the age of piglets at the start of artificial rearing (two to 14 days-old), milk replacer formulation (e.g. inclusion or not of antibiotics or blood products), different types of enclosure (e.g. remaining in the farrowing crate without the sow (Cabrera et al., 2010) vs. Rescue Decks® (Rzezniczek et al., 2015)), milk delivery system (nipples (De Vos et al., 2014) vs. cups (Cabrera et al., 2010; Rzezniczek et al., 2015)), and finally mixing (e.g. Rzezniczek et al., 2015) or not (e.g. De Vos et al., 2014) of the piglets at transfer.

Artificial rearing involves piglets going through the same stressors that normally occur at weaning (abrupt separation from dam, and changes in the social, physical and feeding environments) but at an earlier age than usual. Thus welfare issues associated with weaning could arguably be even greater for artificially-reared piglets (for more details see review by Latham and Mason, 2008). Rzezniczek et al. (2015) showed that artificially-reared piglets displayed the same signs of distress (i.e. vocalisations, growth impairments, development of abnormal behaviours) as early-weaned piglets (e.g. Orgeur et al., 2001). In addition, piglets in artificial-rearing systems showed more aggressive behaviours during the pre-weaning period than piglets reared by a sow. It was hypothesised this was caused by the combination of early mixing, competition caused by the limited space allowance at the milk supply, and recipients' reaction to belly-nosing (Rzezniczek et al., 2015). Because of the feeding conditions and the fact that artificial-rearing enclosures usually have a lower space allowance (i.e. typical space allowance: 1 $m^2$) for piglets compared to farrowing crates (i.e. space allowance: 3.6 $m^2$; Baxter et al., 2012) the behavioural development of piglets may be affected by artificial-rearing. For instance, belly-nosing is rarely observed in sow-reared piglets whereas it develops routinely in early-weaned piglets (Orgeur et al., 2001; Weary et al., 1999; Worobec et al., 1999) and in artificially-reared piglets in milk-cup feeding systems (Rzezniczek et al., 2015; Widowski et al., 2005). Belly-nosing occurs due to redirected suckling behaviour (Widowski et al., 2008) and reflects frustration caused by unfulfilled nursing-related behavioural needs (Weary et al., 1999; Widowski et al., 2005). Manipulation of pen mates, which includes harmful behaviours such as ear- and tail-biting, was higher in frequency and duration in artificially-reared piglets (Rzezniczek et al., 2015), although the causal effects could not be determined as a consistent number of parameters varied between two environments (e.g. space allowance, rooting material, quality of milk, age of weaning from milk). A recent study by Frei et al. (2018) showed that the provision of dummies allowing massage behaviour did not eliminate belly- and body-nosing, which suggests that piglets may be missing tactile properties of the sow's udder.

To date, there are no studies which have adopted a holistic approach to assess the effects of artificial rearing on the welfare of piglets, whereby the behaviour, health and performance of artificially-reared piglets were compared to sow-reared piglets. This study seeks to fill this gap in the scientific knowledge by investigating the effects of artificial rearing on piglets' pre-weaning behaviour, welfare (emotional state, lesions and health) and growth.

## 2. Material and methods

### 2.1. Ethical approval

Ethical approval for this study was granted by Teagasc Animal Ethics Committee (application TAEC113/2016). The experiment was carried out in accordance with the Irish legislation (SI no. 543/2012) and the EU Directive 2010/63/EU for animal experiments.

### 2.2. Animals and experimental design

This experiment was conducted on a commercial farm in County Laois, Ireland, and involved a total of 233 piglets from 20 litters. The genetic background of the piglets was Large White x Hampshire or

Landrace x Hampshire (balanced between treatments). All piglets were born in a conventional farrowing crate (pen: 2.13 x 1.71 m, sow crate: 1.90 x 0.64 m, stocking density: 0.27 $m^2$/piglet, plastic slatted floor) from sows that were induced (2 cc. of Platane®, MSD) at 114 d of gestation. Three handfuls of shredded paper were added to help dry the piglets at birth. Piglets were teeth-clipped and tail-docked (under veterinary advice) at 2 days-old and received an iron injection at 4 days-old. Piglets were vaccinated against porcine mycoplasma hyopneumoniae bacterin (M+PAC®) at 8 and 25 days-old, and against porcine circovirus disease at 25 days-old (Ingelvac CircoFLEX®). Each week two litters of 7 days-old piglets, matched for piglet weight and litter size (n = 11.7±0.2) were selected for inclusion in the study and randomly assigned to one of the two treatments. One litter remained with the sow until weaning (Sow-reared, SR; n = 10 litters, n = 116 piglets) and the other was transferred to an artificial-rearing enclosure (Rescue Deck®, S&R Resources LLC) (Figure 1) and fed milk replacer (Opticare Milk, SwiNco BV, The Netherlands) until weaning (Artificially-reared, AR; n = 10 litters, n = 117 piglets). At transfer to the artificial-rearing enclosure (D0), the heat lamp and the milk cups were already activated and creep feed (Opticare Meal, SwiNco BV, The Netherlands) was available in the trough. Creep feed was also made available to SR piglets in the farrowing pen.

For ethical reasons piglets that did not thrive during lactation (i.e. showed signs of starvation) were removed from the experiment to a non-experimental sow or to another artificial-rearing enclosure for greater attention (i.e. treatment). Records of these removals were used in the analysis of the mortality rate in each system.

In this experiment, weaning was defined as the removal of milk feeding and movement of the piglets to weaner facilities. Because of normal farm practices and needs, there was an age difference at weaning (AR: 26 ± 0.4 d, SR: 29 ± 0.4 d; $F_{1,201}$ = 109.6, P<0.001). Therefore data were collected only until the week preceding weaning and where weaning weights are presented they are adjusted for weaning age to allow a valid comparison.

## 2.3. Nutrition

Details of all diets can be found in supplementary material (Table S1). All sows diets were home-milled. The milk replacer contained 21.5 % crude protein and 9% fat, and dried porcine plasma powder. Milk replacer powder was mixed with hot water (i.e. 150 g/l of water at approximately 55˚C) in a tank which was refilled once or twice daily, depending on daily consumption. All the pipe lines transporting the milk from the tank to the milk cups were flushed once daily with hot water and once weekly with a liquid acid cleaner (Acidsan, Agroserve, GEA Ireland Ltd., Naas, Ireland). During lactation, sows were fed a diet containing 15.5% crude protein, 4.36% crude fat and 3.95% crude fibre for a metabolisable energy of 13.01 MJ/kg and a net energy of 9.4 MJ/kg. Feed allowance to sows increased gradually during lactation, starting with 3 kg/day four days before farrowing and finishing with 8 kg/day at weaning.

The creep feed provided from 7 to 22 days-old contained 19.24% crude protein, 9.54% crude fat and 1.53% crude fibre. Thereafter piglets were given pellets from 22 days-old until weaning, which contained 17.46% crude protein, 6.88% crude fat and 2.67% crude fibre.

## 2.4. Housing

Farrowing pens were equipped with a heat pad (1.55 x 0.37 m, maintained at 30°C), a bowl water drinker, and a trough was provided for solid feed from 7 days-old. Artificial-rearing enclosures (1.40 x 0.71 m, stocking density: 0.08 $m^2$/piglet; fully slatted, plastic-coated expanded metal slats) were equipped with a heat lamp (250 W, that maintained temperature at approximately 30°C), two milk cups (11 cm diameter), a water cup, and a trough for the solid feed. A canopy covered two thirds of the enclosure area, to prevent heat loss. The farrowing house temperature was maintained around 23°C, but the temperature in the room with the artificial enclosures was not controlled.

## 2.5. Measurements

### 2.5.1. Behaviour

Piglet behaviour in both treatments was simultaneously video recorded with a digital camcorder (Panasonic HC-250EB-K, Panasonic®; fixed on a tripod) for 20 min after the transfer of AR piglets (approx. 13:00 h), and 20 min per hour between 09:00 h and 17:00 h, on D5 and D12 (8 videos per day). Thus in total, the behaviour of each litter was recorded by video for a total of 320 min. Hourly 5 min live observations of piglets were also undertaken on the same days by a single observer. Groups of pigs were observed when they were not being video recorded every hour between 09:00 h and 17:00 h.

The same ethogram (Table 1) was used for both video and live observations and all occurrence continuous sampling was used (Martin et al., 1993). Additionally, the behaviour "attempts to escape" was recorded only on D0, when a piglet tried to climb up or jump above the walls of the enclosure, as well as the behaviour "naso-naso contacts", i.e. voluntary (gentle) touch of a piglet's snout against another's snout. Video data were analysed by a single observer (intra-observer reliability = 97%) using the software package The Observer® XT (Noldus, Wageningen, The Netherlands).

### 2.5.2. Qualitative Behavioural Assessment

Qualitative Behavioural Assessment (QBA) was performed as described in the Welfare Quality® assessment protocol for pigs (Welfare Quality®, 2009). Pigs were assessed at 21 days-old (D14) between 12:00 h and 14:00 h, which corresponded to the period with least interference from the staff (no sow feeding, milk tank filling…). Each litter of piglets, randomly selected, was directly observed by a single observer (intra-observer reliability = 90%) for 20 min after which the experimenter scored the 20 fixed descriptors on a 125 mm horizontal valence scale. Each descriptor is associated with a weight (pre-determined in the Welfare Quality® (2009) protocol for pigs) applied to the descriptor's score to allow the calculation of the QBA score. The QBA score provides an assessment of the subjects' emotional state.

### 2.5.3. Mortality, removal and illness

Piglet deaths were recorded from D0 to weaning. Piglets which were removed for ethical reasons allowed additional investigation of the risk of being moved to a non-experimental sow or another artificial-rearing enclosure before weaning, depending on the availability of sows and the type of illness. The occurrence, nature and duration of treatment of piglets for health problems were recorded.

### 2.5.4. Weights

Piglets were weighed individually on the transfer day (designated as D0), the following day (D1), D8, D15 and at weaning. Average daily gain (ADG) was calculated between each of these time points.

### 2.5.5. Lesions

The severity of lesions on piglets' snout, knees, tail and ears was scored when they were weighed. The number of scratches on the ventral or lateral aspects of the piglet's snout was scored using a 4 point scale (0 = no lesions to 3 = snout covered by lesions) developed by Fraser (1975) and modified by Hansson and Lundeheim (2012). Abrasion (presence = 1, absence = 0) and inflammation (presence = 1, absence = 0) on both piglets' front knees were scored using the scale developed by Westin (2013), and overall limb lesion score was calculated per piglet by summing the scores for each knee (score ranging 0-4). The tail lesion scoring system of Harley et al. (2012) was modified: intact tails were scored 0, tails were scored 1 if a puncture wound or swelling (evidence of chewing or biting) was observed and scored 2 if there was a partial or total loss of the tail. Finally the ear lesion scoring system of Diana et al. (2017) was also adapted: intact ears were scored 0, ears with wounds were scored 1, and ears with partial or total loss were scored 2. Each ear was scored separately and the overall score was the sum for each piglet.

### 2.5.6. Tear staining and dirtiness scores

During weighing, the stained area under the eye was scored according to its size relative to the eye's area (DeBoer et al., 2015). Since the scoring system is relative to the pig's eye size, it can be applied to animals of all age on a farm: score 0 was attributed to clean eyes (no sign of staining), score 1 was attributed to barely detectable staining, scores 2 to 4 to eyes where the stained area represented, respectively, <50%, between 50% and 100%, and >100% of the eye area. Both eyes were scored and the average score for the two eyes was analysed. The percentage of face surface covered with dirt (e.g. dried milk, dust, manure…) was scored from 0 for a stainless face to 4 for a face covered at more than 75% with dirt (Minvielle and Le Roux, 2009).

## 2.6. Statistical analyses

Data were analysed using SAS 9.4 (SAS Inst. Inc., Cary, NC). The experimental unit for the analyses of growth performance, survival and health was the pig within litter; and the experimental unit for the analysis of behaviour, emotional state, lesions and coefficient of variation of weights was the litter. The distribution of the data was checked using a univariate model (PROC UNIVARIATE), and data were considered normal if the Shapiro-Wilk and Kolmogorov–Smirnov tests were not significant. General Linear Models (GLM) and Generalized Linear Mixed Models (GLMM) were fitted using the Residual Pseudo Likelihood approximation method. Statistically significant terms were determined when alpha was below 0.05 and tendencies were determined when alpha was between 0.05 and 0.1. Results are reported as means S.E., F-values and t-values, and corresponding degree of freedom (DF, subscript) are reported for overall effects of treatment and pair-wise comparisons, respectively. Replicate was included as a random effect in all models.

For the analysis of behaviour, the 20-min videos and the 5-min live observations were pooled. Rates of behaviours per minute were calculated and analysed using GLMMs (PROC GLIMMIX) with a Poisson distribution and a log link function. All models accounted for the repeated effect of observation within day and the random effect of number of pigs. When the interaction between treatment and day was not significant, due to non-significant differences intra-treatment, treatment differences were considered within each day. This was done using the “slice” statement in the PROC GLIMMIX, which gave the reported F-value and P-value for treatment differences within day.

The QBA scores were analysed using GLM (PROC MIXED). Descriptors’ scores were not normally distributed and analysed using GLMM (PROC GLIMMIX) with a gamma distribution and a logit function. Each model included the random effect of pen. Principal Component Analysis (PCA) was used to compute the descriptor scores into principal components, which explain the variability in QBA score between litters. The first two principal components with eigenvalues above 1.0 were retained to produce a two-dimensional word chart, where the 20 descriptors’ eigenvector values (i.e. quantification of the weight of the descriptor) were plotted on the two principal components axes. This word chart was then used to interpret the first two principal components and thus, how the pigs were perceived. Each litter of AR and SR piglets received a score on each of the two main principal components, which allowed defining clusters. Survival, removal and health data were binary, thus these variables were analysed using GLMMs with a binary distribution and logit link function.

Weights, average daily gains (ADG) and coefficient of variation (CV) of weights were normally distributed with regards to their residuals and analysed using GLMs. For analysis of weight the initial (i.e. D0) weight was used as a covariate. Day was included as a repeated effect in analysis of weights and CV. For weaning weight the age of the pig was used as a covariate, as there were differences in weaning age.

All lesion, dirtiness and tear staining scores were averaged per litter and analysed using GLMs (PROC MIXED), accounting for repeated effect of day.

# 3. Results

## 3.1. Behaviour

All descriptive data (number of observations, minimum, maximum, mean, standard deviation and standard error) are presented in supplementary material (Tables S2 and S3).

3.1.1. Behaviour at transfer

Due to technical failure (malfunctioning of the camera), one replicate could not be observed. Belly-nosing, play-fighting and naso-naso contacts were not observed in either treatment during the 20 minutes following assignment to treatments (i.e. transfer of AR piglets to the artificial-rearing enclosure and SR piglets remaining with their mothers). There was only one AR piglet which attempted to escape after transfer of the litter to the artificial-rearing enclosure, thus these data were not analysed. There were no other differences in the behaviours observed between AR and SR piglets at the time of transfer (Figure 2).

3.1.2. Routine behavioural observations

Table 2 summarises the results of routine behavioural observations.

Over the two observation days, the rate per minute of belly-nosing was higher in AR piglets than in SR piglets (0.72 ± 0.100 vs. 0.01 ± 0.006, respectively; $F_{1,76.53} = 42.25$, $P<0.001$). Visits to the milk cup in AR piglets were more frequent than nursing bouts in SR piglets (0.35 ± 0.273 vs. 0.16 ± 0.124, respectively; $F_{1,73.8} = 38.42$, $P<0.001$) and AR piglets performed more nursing-related displacements per minute than SR piglets (0.27 ± 0.028 vs. 0.12 ± 0.019, respectively; $F_{1,79} = 19.32$, $P<0.001$). Although play-fighting behaviour frequency did not differ between AR and SR piglets (1.00 ± 0.120 vs. 1.20 ± 0.132, respectively; $F_{1,80.09} = 1.23$, $P > 0.1$), SR piglets played alone more frequently than AR piglets (0.25 ± 0.044 vs. 0.10 ± 0.027, $F_{1,88.99} = 8.29$, $P<0.005$). Oral manipulation of the tails (0.08 ± 0.016 vs. 0.02 ± 0.006, respectively; $F_{1,58.54} = 15.63$, $P<0.001$) and ears (0.23 ± 0.025 vs. 0.12 ± 0.018, respectively; $F_{1,91.95} = 12.79$, $P<0.001$) were more frequent in AR piglets than in SR piglets. The rate of exploration behaviour per minute was higher in SR piglets than in AR piglets (0.48 ± 0.053 vs. 0.34 ± 0.044, respectively; $F_{1,99.42} = 4.52$, $P<0.05$).

3.2. Qualitative Behavioural Assessment

The AR piglets had a lower QBA score than SR piglets (43.1 ± 6.21 vs. 77.8 ± 6.21; $F_{1,9} = 2.42$, $P<0.005$), which indicates a poorer emotional state. In particular, AR piglets scored lower than SR piglets on positive terms (associated with positive weights) such as active ($P<0.05$), content ($P<0.05$), enjoying ($P<0.001$), playful ($P<0.005$), positively occupied ($P<0.05$), lively ($P<0.01$) and happy ($P<0.01$); and scored higher on negative terms (associated with negative weights) such as bored ($P<0.05$), irritable ($P<0.001$) and aimless ($P<0.001$). However, SR piglets had a higher score for the term fearful compared to AR piglets ($P<0.005$) (Table 4). From the PCA, two principal components (PC) were retained, explaining 33% and 15% of the total variation in QBA score (Figure 3a; Table 4). PC1 was mostly characterised by descriptors related to positive feelings: enjoying (0.37), playful (0.36), happy (0.35), lively (0.29), content (0.29), active (0.28), and positively occupied (0.26) (Table 4). PC2 was mostly characterised by descriptors related to low arousal: calm (0.49), indifferent (-0.46), listless (0.30), bored (0.30) and fearful (-0.29) (Table 4). The AR and SR litters clustered clearly (Figure 3b), and they mostly differed by their loadings on PC1. Indeed most of the AR litters had lower loadings on PC1 (-1.71 to 0.08) compared to SR piglets (-0.11 to 1.56), meaning that they were perceived as less enjoying, active, content, happy, playful, lively and positively occupied. The clustering of litters on PC2 axis was less clear, but most (8/10) AR litters had a loading above 0 while most (6/10) SR litters had a loading below 0. This would suggest that AR piglets were perceived as more calm, bored and listless and less indifferent and fearful than SR piglets.

### 3.3. Survival, removal and illness

Only one piglet died in each treatment. Very few piglets had to be removed from the experiment for ethical reasons and there was no difference between treatments (SR: 5.9 ± 2.32 %, AR: 7.2 ± 2.66 %). Finally, over the whole experiment, 27 and 18 illness events were recorded in AR piglets and SR piglets, respectively. There was large variation in the percentage of piglets treated for illness or injury in the different treatment groups, but no significant differences were found (SR: 11.86 ± 6.5 %, AR: 16.95 ± 8.8 %, $F_{1,16.65} = 0.22$, $P>0.6$). However, AR litters had a higher percentage of piglets suffering from diarrhoea (SR: 2.7 ± 1.97 %, AR: 13.7 ± 7.84 %, $F_{1,232}$=12.2, P<0.001) and a lower percentage of lame piglets (SR: 7.1 ± 3.41 %, AR: 0.7 ± 0.7 % , $F_{1,232}$=5.33, P<0.05), compared to SR litters.

## 3.4. Weights and growth

AR piglets tended to be heavier than SR piglets before transfer to the artificial-rearing enclosure, but even after adjusting for initial weight in the models, from D1 and until weaning AR piglets were lighter than SR piglets (Table 3). AR pigs had a lower average daily gain (ADG) during the pre-weaning period (0.24 ± 0.005 kg/d vs. 0.27 ± 0.005 kg/d; $F_{1,199}$ = 12.1, P<0.001) (Table 3). In fact, AR pigs' ADG was reduced during the 24 h following their transfer to the artificial-rearing enclosure (Table 3). During the remainder of the lactation period, the difference in ADG of AR compared to SR piglets decreased (Table 3). The coefficient of variation (CV) of weight did not differ between SR and AR litters (Table 3).

## 3.5. Lesions

On the day of transfer (D0), AR and SR piglets did not differ in lesion scores for the snout, ear, tail and limbs. Overall (D0, D1, D8 and D15 taken together), AR piglets had lower lesion scores for the limbs (0.2 ± 0.05 vs. 0.3 ± 0.05, respectively; $F_{1,10.1}$ = 5.89, P<0.05) and the ears (0.1 ± 0.04 vs. 0.3 ± 0.04; $F_{1,14.5}$=24.89, P<0.001), but higher tail lesion scores (0.3 ± 0.04 vs. 0.1 ± 0.04; $F_{1,34.5}$ = 15.54, P<0.001) compared to SR piglets. Snout lesions did not differ (0.06 ±0.023 vs. 0.10 ± 0.023, respectively; $F_{1,24.6}$ = 1.59, P>0.1). Details of treatment differences per day can be found in Supplementary Material (Table S4).

## 3.6. Tear staining score and dirtiness score

On D0, AR and SR piglets had similar tear staining scores for both eyes ($t_{18}$ = 0.51 and $t_{11.7}$ = -0.40, P>0.05). Overall (D0, D1, D8 and D15 taken together), AR piglets had lower tear staining scores (0.43

± 0.046 vs. 0.97 ± 0.046; $F_{1,19.1}$ = 68.4, P<0.001) and higher dirtiness scores (1.18 ± 0.098 vs. 0.69 ± 0.098; $F_{1,17.4}$ = 23.38, P<0.001) than SR piglets. Details of treatment differences per day can be found in Supplementary Material (Table S5).

# 4. Discussion

This study demonstrated that artificial rearing had a negative impact on piglets' behaviour, growth and some aspects of welfare during lactation, compared to piglets reared with their sow.

With the exception of one AR piglet which attempted to jump out of the artificial-rearing enclosure several times, once transferred to the enclosure, the behaviour of AR piglets was not different to SR piglets (that stayed with their mother). As expected, AR piglets performed belly-nosing more frequently than SR piglets (Frei et al., 2018; Rzezniczek et al., 2015). In agreement with the study of Rzezniczek et al. (2015), higher occurrences of negative behaviours (e.g. ear- and tail oral manipulation) were observed in AR piglets. They also performed more nursing-related displacements which, together with belly-nosing, disturbed the feeding episodes of receiving piglets. They played alone less than SR piglets, probably because of the lower space allowance which did not facilitate running. The AR piglets performed play-fighting as much as SR piglets, which disagrees with the results of Rzezniczek et al. (2015) who observed more play-fighting in sow-reared piglets than in artificially-reared piglets. However, Rzezniczek et al. (2015) had seven piglets per artificial-rearing enclosure and approximately 11 piglets per sow, and thus the number of partners (i.e. opportunities to play) was greater in SR litters. Typical play-invite behaviours involve play behaviours clearly directed at a recipient, and rejection involves turning away and not-engaging with the "actor" (Martin et al., 2015). In the present study, the stocking density of the artificial-rearing enclosure was higher than in the study of Rzezniczek et al. (i.e. 0.08 $m^2$/piglet vs. 0.15 $m^2$/piglet). This likely increased the number of unavoidable encounters leading to play-fights as play rejections may have been hampered by the lack of space to avoid engagement. Finally the piglets in the study of Rzezniczek et al. (2015) were younger (i.e. 2-6 days-old) than in the present study when transferred to the artificial-rearing enclosure, which could have had a greater impact on their behavioural development.

AR piglets experienced a growth check directly following transfer to the artificial-rearing enclosure, had a lower growth rate until D15 than SR piglets, and consequently, a lower weaning weight. The initial growth check experienced by the piglets is likely due to the change in diet and delivery method, similarly to what is experienced by all piglets at weaning. In addition, the higher occurrence of diarrhoea in artificially-reared piglets, the higher frequency of belly-nosing, and displacements at the feeder, may have prevented the compensatory growth, which has been previously observed in artificially-reared piglets. Belly-nosing alters the feeding and drinking patterns of both performers and recipients (Torrey and Widowski, 2006; Widowski et al., 2008). In the present study, belly-nosing was usually performed during feeding episodes and, indeed, disrupted feeding bouts of recipients (personal observation). This could partly explain the surprising discrepancy between lower growth rates of AR piglets, and their higher frequency of visits to the milk cup. In addition, the milk cups could only facilitate feeding for up to 6 pigs simultaneously (3 per cup), which increased competition during feeding episodes in AR piglets, as supported by the higher frequency of displacements observed at the milk cup. These displacements resulted in milk projections which, together with higher levels of diarrhoea, are likely to have contributed to the higher levels of dirtiness of AR piglets.

Tear-staining is a non-invasive technique meant to assess stress level of pigs (DeBoer et al., 2015). Our tear staining result indicates AR piglets were less stressed than SR piglets (as indicated by lower tear-staining scores), which is not in agreement with our other welfare and performance results. Nevertheless, our tear-staining results should be interpreted with caution, as this is the first study using tear-staining to assess stress in piglets, and differences in environmental conditions (e.g. humidity, stocking density…) could have influenced the staining. More validation work is needed to determine whether this method to be considered a reliable indicator of welfare status (DeBoer et al., 2015; Telkänranta et al., 2015).

Tail lesions were greater in AR piglets, probably due to the higher frequency of oral manipulation of tail in these litters. However, surprisingly, AR piglets had lower ear lesion scores even though oral manipulation of the ears was more frequently performed in this treatment. Limb lesions were lower in AR piglets, compared to SR piglets, until weaning. This could be due to AR piglets not needing to kneel to suckle at the udder, which leads to knee abrasion (Boyle et al., 2000).

The emotional state of AR piglets, as assessed by QBA, was poorer than SR piglets. Piglets mainly differed in descriptors related to positive feelings (i.e. happy, content, positively occupied, enjoying, playful, lively), although the loadings were rather low probably due to the low sample size. Nevertheless, the results are in alignment with those from the time budget observations; lower positive feelings could be due to, or reflective of, a higher occurrence of the negative behaviours (e.g. oral manipulation of tails and ears, belly-nosing) observed, or disturbance of feeding episodes and poorer digestive health, as evinced by higher diarrhoea levels, in AR piglets. Obviously the lower space allowance could influence piglet welfare (Cornale et al., 2015), but it can also be speculated that the absence of maternal care, although limited in the pig, could be a causal factor of AR piglets' lower emotional state. Unfortunately, there is no scientific study on the sow-piglet bond and the importance of maternal care for piglets, beyond a nutritional point of view. However naso-naso contacts between the sow and the piglets have been reported as a form of social bond (Blackshaw and Hagelsø, 1990) or play (Horback, 2014). This deserves more attention, especially when evaluating the use of artificial-rearing systems.

Although the percentage of piglets with a health issue was not affected by treatment, there were treatment differences with regard to specific disorders health events: a greater percentage of AR piglets suffered from diarrhoea and a lower percentage of AR piglets were lame, compared to SR piglets. The incidence of lameness in SR piglets can be explained by the risk of being stepped on by the sow and exposure to the sow slats which can be injurious to piglets (Lewis et al., 2005). The higher incidence of diarrhoea in AR piglets could have been initiated by the stress caused by separation from their mother at 7 days of age, exacerbated by the change of environment and by adaptation to the milk replacer. Chronic stress after separation from their mother could lead to intestinal mucosal barrier dysfunction in AR piglets, as observed in early-weaned piglets (Smith et al., 2009). In addition, the higher stocking density and higher humidity level (personal observation) in the artificial-rearing enclosure may promote bacterial growth (Banhazi et al., 2009; Roque et al., 2016). Milk replacer formulations differ and may include immune components (e.g. from porcine plasma) to help protect piglets' health. Because AR piglets in the present study had higher occurrence of diarrhoea, it can be speculated that the immune components of the milk replacer may not be as efficiently absorbed by the piglets as compounds of sow milk (Hurley, 2015), possibly because of the origin of the immune material (i.e. plasma instead of milk).

The analytical composition (e.g. protein level, addition of blood plasma or immune material) of the milk replacer used could be a major cause of inconsistency in results from studies on artificial rearing. In particular, porcine plasma in the milk replacer can act as a growth promotor but may also influence the occurrence of diarrhoea in AR piglets (Van Dijk et al., 2001). Supporting the latter hypothesis, Touchette et al. (2002) found that pigs fed a diet containing 7% of spray-dried plasma for one week post-weaning (i.e. 14 to 21 days-old) had a depressed immunity compared to pigs fed a normal diet. The occurrence of diarrhoea and the number of medications administered to piglets was not measured in other studies, and deserves more attention when evaluating the effects of artificial rearing. It is also worth noting that plasma products are not legal in all countries, because of the threat they pose to biosecurity (Van Dijk et al., 2001) and because of the ethical concern about feeding animal products to animals, despite the omnivorous characteristic of pigs.

Artificially-reared piglets (i.e. from 3 days-old) performed belly-nosing routinely if fed by a cup system, less if fed by a nipple drinker system, but not if fed by an artificial udder (i.e. baby-bottle nipples mounted in front of a water-filled bag) (Widowski et al., 2005). In addition, piglets with a nipple drinker displayed stereotypic snout rubbing on the wall behind the drinkers, possibly showing their motivation to perform massage behaviour as a part of natural nursing behaviour (Widowski et al., 2005). This suggests that synchronous feeding is an important feature of nutrition in piglets and that asynchronous feeding could lead to development of abnormal behaviours. The artificial udder seemed to better permit the behaviours related to feeding (suckling, massaging and nosing), and may illicit suckling through its tactile properties (Welch and Baxter, 1986). However, feeding systems using nipples may require more human intervention to help the piglets to learn how to use them compared to cup systems (Widowski et al., 2005), increasing time and labour costs, and may therefore be impractical.  Rzezniczek et al. (2015) trained artificially-reared piglets to drink from the milk cups, which may have promoted piglets' growth (unpublished data, Weber et al. (2015)). Therefore the feeding systems used in AR studies could have influenced results, and studies to address systems allowing synchronous feeding and providing an imitation udder are warranted.

## 5. Conclusion

Artificial rearing has detrimental effects on piglets' behaviour, welfare and growth. Artificially-reared piglets performed more agonistic behaviours such as oral manipulative behaviours (ear and tails) and belly-nosing. The emotional state of artificially reared-piglets was lower than that of SR piglets. They also had a lower growth rate and a higher incidence of diarrhoea, compared to sow-reared piglets. Together, our results suggest that artificial-rearing systems need to be improved to promote appropriate/natural behavioural development of piglets and improve their welfare and performance.

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**Table 1** Description of behaviours observed on D0, D5 and D12.

| **Behaviour** | **Description** |
|---|---|
| Belly-nosing | A rhythmic up-and-down movement with the snout on the belly or soft tissue of another piglet (Widowski et al., 2005), especially performed on the skin behind the ear and on the abdomen between the front and the hind limbs (Rzezniczek et al., 2015). Does not include belly-sucking. |
| Displace | Piglet pushes another one to gain access to a milk cup (AR piglets) or teat (SR piglets) |
| Milk | Piglet has its snout in the milk cup/suckle a teat at milk let-down |
| Oral manipulation of ears and tail | Having another piglet's ear or tail in the mouth (Widowski et al., 2005). This behaviour would thus include any chewing, nibbling or biting of ears or tail of a pen-mate. |
| Explore | Snout touching or rooting on floor and walls, or chewing on fixtures of the environment (Melotti et al., 2011) |
| Play-fighting | Nudge, chase, push, push-overs (Blackshaw et al., 1997; Martin et al., 2015). |
| Play alone | Spring/leap, pivot, toss head, run, rolling (Blackshaw et al., 1997; Martin et al., 2015) |

**Table 2** Means (± S.E.) occurrence of behaviour per minute of observations (20-min video and 5-min live observations pooled) of sow-reared piglets (SR) or artificially-reared piglets (AR) at 12 days-old (D5) and 19 days-old (D12). AR piglets were removed from their mother at 7 days-old and fed milk replacer in a Rescue Deck® until weaning. SR piglets remained with their mother until weaning.

| | Sow-Reared | Artificially-Reared | F-value | P-value |
|---|---|---|---|---|
| **D5** | | | | |
| Belly-nosing[1] | 0.00 (±0.005) | 0.63 (±0.099) | F(1,87.98) = 17.27 | <0.001 |
| Displace[2] | 0.12 (±0.026) | 0.25 (±0.037) | F(1,93.37) = 7.22 | <0.01 |
| Ear oral manipulation[3] | 0.12 (±0.025) | 0.33 (±0.041) | F(1,105.3) = 17.1 | <0.001 |
| Explore[4] | 0.39 (±0.066) | 0.37 (±0.064) | F(1,109.8) = 0.06 | NS |
| Milk cup visits/nursing[5] | 0.16 (±0.125) | 0.33 (±0.255) | F(1,87.66) = 16.11 | <0.001 |
| Play-fighting[6] | 1.07 (±0.173) | 1.07 (±0.173) | F(1,93.96) = 0 | NS |
| Play alone[7] | 0.27 (±0.064) | 0.10 (±0.038) | F(1,99.06) = 4.73 | <0.05 |
| Tail oral manipulation[8] | 0.01 (±0.007) | 0.10 (±0.023) | F(1,75.83) = 12.97 | <0.001 |
| **D12** | | | | |
| Belly-nosing | 0.00 (±0.010) | 0.86 (±0.129) | F(1,87.98) = 39.05 | <0.001 |
| Displace | 0.12 (±0.026) | 0.30 (±0.041) | F(1,93.37) = 13.24 | <0.001 |
| Ear oral manipulation | 0.12 (±0.024) | 0.16 (±0.029) | F(1,105.3) = 1.45 | NS |
| Explore | 0.61 (±0.082) | 0.31 (±0.059) | F(1,109.8) = 8.05 | <0.01 |
| Milk cup visits/nursing | 0.16 (±0.126) | 0.38 (±0.294) | F(1,87.66) = 24.12 | <0.001 |
| Play-fighting | 1.34 (±0.194) | 1.07 (±0.173) | F(1,93.96) = 2.55 | NS |
| Play alone | 0.23 (±0.059) | 0.10 (±0.038) | F(1,99.06) = 3.64 | 0.06 |
| Tail oral manipulation | 0.02 (±0.009) | 0.06 (±0.017) | F(1,75.83) = 4.73 | <0.05 |

[1] Effect of treatment x day on belly nosing: $F_{(1,102.8)}$=0.59, P>0.1

[2] Effect of treatment x day on displace: $F_{(1,112.9)}$=0.41, P>0.1

[3] Effect of treatment x day on ear oral manipulation: $F_{(1,121.9)}$=3.27, P=0.07

[4] Effect of treatment x day on explore: $F_{(1,121.6)}$=3.21, P=0.08

[5] Effect of treatment x day on milk cup visits/nursing: $F_{(1,106.7)}$=0.32, P>0.1

[6] Effect of treatment x day on play-fighting: $F_{(1,112.4)}$=1.28, P>0.1

[7] Effect of treatment x day on play alone: $F_{(1,110.8)}$=0.02, P>0.1

[8] Effect of treatment x day on tail oral manipulation: $F_{(1,107.3)}$=1.52, P>0.1

**Table 3** Weight, Average Daily Gain and Coefficient of Variation of litter weight artificially-reared (AR) and sow-reared (SR) piglets. AR piglets were removed from their mother at 7 days-old and fed milk replacer in the artificial-rearing enclosure until weaning, while SR piglets remained with their mother. D0 is the day of transfer in the artificial-rearing enclosure for AR piglets, at 7 days-old. Weaning was at 26 ± 0.4 days-old for AR piglets and 29 ± 0.4 days-old for SR piglets and was accounted for in the analysis.

| | SR | AR | S.E. | DF | t-value | P-value |
|---|---|---|---|---|---|---|
| **Weight (kg)** | | | | | | |
| D0 | 2.86 | 2.73 | 0.100 | 269 | -3.08 | N.S. |
| D1 | 3.32 | 3.13 | 0.126 | 211 | 8.51 | <0.001 |
| D8 | 4.91 | 4.33 | 0.060 | 257 | 8.17 | <0.001 |
| D15 | 6.60 | 5.85 | 0.108 | 217 | 5.98 | <0.001 |
| Weaning | 7.97 | 6.53 | 0.153 | 256 | 9.79 | <0.001 |
| **Average Daily Gain (kg/day)** | | | | | | |
| D0-D1 | 0.23 | 0.05 | 0.014 | 231 | 9.26 | <.0001 |
| D1-D8 | 0.28 | 0.22 | 0.014 | 224 | 5.68 | <.0001 |
| D8-D15 | 0.29 | 0.26 | 0.019 | 195 | 2.02 | <0.05 |
| D15-Weaning | 0.27 | 0.29 | 0.010 | 167 | -1.43 | N.S. |
| D0-Weaning | 0.27 | 0.24 | 0.005 | 199 | 3.48 | <0.001 |
| **Coefficient of variation** | | | | | | |
| D0 | 0.12 | 0.10 | 0.007 | 16.1 | 2.39 | N.S. |
| D1 | 0.13 | 0.11 | 0.009 | 19.9 | 1.66 | N.S. |
| D8 | 0.14 | 0.14 | 0.014 | 16.6 | -0.06 | N.S. |
| D15 | 0.14 | 0.13 | 0.015 | 19 | 0.4 | N.S. |
| Weaning | 0.14 | 0.09 | 0.013 | 15.5 | 2.97 | N.S. |

**Table 4** Mean (±S.E.) scores of the descriptors used in the Qualitative Behavioural Assessment (QBA) of artificially-reared (fed milk replacer away from their mother, from 7 days of age until weaning) and sow-reared piglets (normal lactation with mother); and eigenvectors values of the descriptors on the principal components (PC) retained from the computation of the QBA terms scores (PCA analysis).

| | | | Eigenvalue | | 6.33 | 3.89 |
|---|---|---|---|---|---|---|
| | | | % of variance explained | | 33% | 15% |
| | Sow-reared | Artificially-reared | F-value | P-value | **PC1** "Positive feelings" | **PC2** "Low arousal" |
| Active | 66.9 ± 12.55 | 32.9 ± 6.17 | F(1,9) = 7.98 | <0.05 | 0.28 | -0.20 |
| Relaxed | 62.2 ± 7.82 | 62.1 ± 7.81 | F(1,9) = 0 | N.S. | 0.05 | 0.04 |
| Fearful | 36.7 ± 7.5 | 12.6 ± 2.58 | F(1,9) = 19.1 | <0.005 | 0.23 | -0.29 |
| Agitated | 9.3 ± 5.21 | 2.1 ± 1.18 | F(1,9) = 3.53 | 0.09 | 0.21 | -0.08 |
| Calm | 71.8 ± 10.34 | 80.4 ± 11.57 | F(1,9) = 0.37 | N.S. | 0.02 | 0.49 |
| Content | 78.3 ± 5.24 | 62.3 ± 4.17 | F(1,9) = 5.84 | <0.05 | 0.29 | 0.20 |
| Tense | 0.0 ± 0.02 | 0.0 ± 0.02 | F(1,9) = 0.05 | N.S. | 0.05 | -0.15 |
| Enjoying | 84.0 ± 7.59 | 40.5 ± 3.66 | F(1,9) = 32.62 | <0.001 | 0.37 | 0.06 |
| Frustrated | 7.8 ± 2.18 | 12.4 ± 3.46 | F(1,9) = 1.38 | N.S. | -0.14 | -0.21 |
| Sociable | 84.2 ± 5.73 | 74.4 ± 5.06 | F(1,9) = 1.93 | N.S. | 0.24 | 0.05 |
| Bored | 5.2 ± 1.81 | 22.4 ± 7.81 | F(1,9) = 8.77 | <0.05 | -0.27 | 0.30 |
| Playful | 83.5 ± 18.57 | 22.6 ± 5.03 | F(1,9) = 17.26 | <0.005 | 0.36 | -0.08 |
| Positively-occupied | 76.0 ± 5.77 | 56.7 ± 4.30 | F(1,9) = 7.45 | <0.05 | 0.26 | 0.06 |
| Listless | 0.0 ± 0.00 | 0.0 ± 0.00 | F(1,9) = 1 | N.S. | 0.10 | 0.30 |
| Lively | 85.8 ± 8.25 | 53.7 ± 5.16 | F(1,9) = 12.83 | <0.01 | 0.30 | -0.09 |
| Indifferent | 18.4 ± 10.28 | 13.4 ± 7.48 | F(1,9) = 0.16 | N.S. | -0.07 | -0.46 |
| Irritable | 0.0 ± 0.00 | 4.3 ± 6.02 | F(1,9) = 401.95 | <0.001 | -0.13 | 0.13 |
| Aimless | 0.0 ± 0.00 | 4.7 ± 1.94 | F(1,9) = 210.3 | <0.001 | -0.11 | -0.22 |
| Happy | 80.7 ± 7.28 | 52.7 ± 4.76 | F(1,9) = 12.33 | <0.01 | 0.35 | 0.18 |
| Distressed | 0.0 ± 0.00 | 0.0 ± 0.00 | F(1,9) = 1 | N.S. | 0.00 | 0.00 |

**Figure 1** Schematic representation (a) and picture (b) of an artificial-rearing enclosure (Rescue Deck®, S&R Resources LLC). *TResearch* magazine, Teagasc. Graphic prepared by ThinkMedia.

**Figure 2** Mean (± S.E.) occurrence of behaviours per minute, during the 20 min following transfer of artificially-reared (AR) piglets in the artificial-rearing enclosure. Sow-reared (SR) piglets remained with their mother.

**Figure 3** Graphical representation of Principal Component Analysis (PCA) outcomes for Qualitative Behavioural Assessment (QBA) of artificially-reared (AR) and sow-reared (SR) piglets. QBA was done on D14, when piglets were 21 days-old. AR piglets were removed from their mother at 7 days-old and fed milk replacer in the artificial-rearing enclosure until weaning, while SR piglets remained with their mother.

a) Eigenvector values of each descriptor on the two principal components retained from the PCA. Principal component 1 represented 33% of the total variation of QBA score, and principal component 2 represented 15% of the total variation of the QBA score.

b) Loadings of the AR and SR litters along the two principal components retained from the PCA.