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Comparison of the behaviour of piglets raised in an artificial rearing system or reared by the sow

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ABSTRACT

Over the last 15 years, rising sow fertility has led to a considerable increase in litter size. As a consequence, the number of live born piglets may outnumber the number of functional teats, and surplus piglets are removed from the sow at the age of 3–6 days and fed with artificial milk. The objective of this study was to compare the behaviour of piglets raised in a commercially available artificial rearing system (group size: seven piglets) with that of piglets reared by the sow in a loose farrowing pen (seven focal piglets observed per litter). The behaviour of 98 piglets raised artificially (7 batches) and 82 piglets reared by the sow (6 batches) was videotaped on days 4, 11 (artificially raised piglets only) and 18 after introduction of the piglets to the artificial rearing system. Belly nosing, manipulation of a pen mate, play-fighting, aggressive behaviour and resting were assessed by continuous focal observation twice a day in the periods from 05:00 to 10:15 and from 13:00 to 18:15. Data were analysed by using linear mixed-effects models.

Belly nosing was hardly ever observed in piglets reared by the sow, whereas the duration as well as the frequency of this behaviour increased between days 4 and 18 in piglets raised artificially. Moreover, artificially raised piglets spent more time manipulating a pen mate, showed less play-fighting, exhibited more aggressive behaviour and had shorter resting bouts compared with piglets reared by the sow. Finally, total duration of resting decreased from day 4 to day 18 in artificially raised piglets and increased in piglets reared by the sow.

It is concluded that piglets removed from the sow at an early age and raised artificially redirect massaging behaviour to their pen mates, resulting in high levels of belly nosing and indicating impaired animal welfare. Moreover, the small space allowance in the tested artificial rearing system may additionally account for behavioural differences observed between artificially raised piglets and piglets reared by the sow in a loose farrowing pen.

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1. Introduction

Over the last 15 years, rising sow fertility has led to an increase in litter size (Tomiyama et al., 2011; Vidović et al., 2012; Rutherford et al., 2013). Increased litter size is associated with more variation in piglets' birth weight and reduced pre-weaning survival (Milligan et al., 2002; Quiniou et al., 2002; Wolf et al., 2008; Akdag et al., 2009; Andersen et al., 2011). In addition, competition at the sow's udder is increased, and the number of live born piglets may outnumber the number of functional teats (Milligan et al., 2001; Andersen et al., 2011).

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There are several management approaches to deal with surplus piglets (Baxter et al., 2013; Rutherford et al., 2013). Large litters are split into two groups by removing the heavy and strong piglets for a short period of time, thus facilitating access to the udder for the light and weak piglets ('split suckling'; Kyriazakis and Edwards, 1986; Baxter et al., 2013). A common method used to balance litter size between sows is cross-fostering (Cecchinato et al., 2008; Baxter et al., 2013). Piglets are relocated from their biological mother sow to another lactating sow with fewer piglets (Baxter et al., 2013). Furthermore, nurse sows may be used to rear a second litter composed of piglets of other sows once their own piglets have been weaned (Baxter et al., 2013). Finally, surplus piglets can be removed from the sow within a few days after birth, after colostrum intake, and raised in artificial piglet rearing systems (Baxter et al., 2013). They are first fed artificial milk, which is later replaced by solid feed (Baxter et al., 2013). The present study focused on one such artificial rearing system that is commercially available and was conducted according to the Swiss authorisation procedure for mass-produced farm animal housing systems that evaluates housing equipment with regard to animal welfare (Wechsler, 2005). Behaviour of piglets raised in this system was compared with piglets that remained with their mother. The two systems differed in several aspects. The most important of these aspects were the earlier separation from the mother, feeding on artificial milk, the earlier weaning from milk, the smaller group size, the smaller space allowance (and therefore a higher density), the lower quality of bedding material, and being mixed with non-litter mates in the piglets raised artificially compared to the piglets reared by the sow.

One of the said differences that seems relevant and was investigated previously concerns the so-called "early weaning". Weaning of piglets is associated with major changes in their housing conditions likely affecting their welfare. The piglets are separated from the sow, start to ingest solid feed early and are usually mixed with unfamiliar piglets in an unknown environment (Worobec, 1997; Gardner, 2000). Various studies on the effects of weaning at an age of 3 weeks have shown that piglets develop an abnormal behaviour pattern termed "belly nosing" (van Putten and Dammers, 1976; Fraser, 1978; Worsaae and Schmidt, 1980). The behaviour consists of rhythmic up-and-down movements with the snout directed to the body of a pen mate (Fraser, 1978). As a general pattern, it was found that belly nosing increases in frequency and duration as weaning age decreases (Metz and Gonyou, 1990; Bøe, 1993; Jarvis et al., 2008). For example, Gonyou et al. (1998) reported that piglets weaned at the age of 12 days spent more time belly nosing than piglets weaned at the age of 21 days. Similarly, piglets weaned at 7 days of age showed a higher level of belly nosing than those weaned at 14 or 21 days in a study by Worobec et al. (1999).

Mixing with non-littermates, crowding, and lack of straw after weaning may have additional effects on the piglets' behaviour (Dybkjaer, 1992). For example, van Putten and Dammers (1976) as well as Bøe (1993) reported that piglets weaned at 3–4 weeks of age and kept in pens lacking environmental stimuli, such as bedding material, to elicit exploratory behaviour manipulated pen mates by nibbling, sniffing, rooting, or chewing. With decreasing space allowance, piglets weaned at the age of 2–3 weeks were found to show more piglet-directed nosing (Gardner et al., 2001), to play less (Worsaae and Schmidt, 1980), to perform more aggressive behaviour (Worsaae and Schmidt, 1980), and to spend less time lying (Gardner et al., 2001).

Only few studies so far have investigated the behaviour of piglets separated from the sow within the first week postpartum. Orgeur et al. (2001) found that belly nosing and aggressive behaviour was more frequent in piglets reared artificially from day 6 onwards compared with piglets reared by the sow. Widowski et al. (2005) investigated the behaviour of piglets removed from the sow 56 to 92 h after birth and housed in nursery isolator tanks divided into a feeding, dunging, and resting area. They provided the piglets with artificial milk four times per day by using different feeding systems and reported that piglets offered milk in a plastic trough spent more time belly nosing as well as nosing, chewing or sucking ears and tails of pen mates than piglets fed artificial milk through baby-bottle nipples or an artificial udder.

The objective of this study was to compare the behaviour of piglets raised in two different rearing environments. The animals were either removed from the sow at the young age of 3–6 days and raised in a commercially available artificial piglet rearing system (group size: 7 piglets) or reared by the sow in a loose farrowing pen (7 focal piglets observed per litter). The study was conducted on an experimental farm on which we had full control of the two different rearing environments and several batches of animals were included. We specifically expected a high incidence of belly nosing in artificially raised piglets and were further interested in differences in manipulation of pen mates, play-fighting, and aggressive as well as resting behaviour.

2. Materials and methods

2.1. Animals, farrowing pens, and experimental design

A total of 180 purebred Swiss Large White piglets stemming from seven batches were investigated between March 2012 and September 2013. Piglets were born in loose farrowing pens measuring 2.3 × 3.2 m. The pens were partitioned by a timber wall (1.4 m long and 1.1 m high) into a nesting area with a straw-bedded solid concrete floor (2.3 × 1.4 m) and a dunging area with a partly slatted floor (2.3 × 1.2 m). Several handfuls of cut straw were added daily to the nesting area. The pens were equipped with a nipple drinker for the sow, a bowl drinker for the piglets, a feeding trough, and a piglet box (1.4 × 0.5 m; height: 0.5 m). The piglet box provided a heating plate fitted in the lid and a straw-bedded rubber mat on the floor. Within 24 h after birth, all piglets were marked individually with numbered ear tags. All male piglets were castrated within the first 2 weeks of age under analgesia and isoflurane anaesthesia. According to Swiss animal welfare legislation, tail docking and canine teeth clipping were not carried out. For the experiment, piglets were assigned to two treatment groups: artificially raised piglets ($n = 98$) and piglets reared by the sow ($n = 82$).

During seven batches, 14 piglets from three to five litters per batch (seven male and seven female piglets) were removed from the sow 2 days after the birth of the last piglet in a given batch and distributed to two units of a commercially available artificial piglet rearing system, so-called 'Rescue Decks' (Rescue Deck® System, S&R Resources LLC, USA). This procedure ensured that all piglets received sufficient colostrum. The 14 piglets per batch were distributed in such a way that each Rescue Deck housed seven piglets from two to four litters (with a maximum of five piglets from the same litter to ensure at least some minimal mixing that reflected the practical use of the Rescue Decks). They were healthy and normally sized, and piglets assigned to the two Rescue Decks were balanced in respect to sex and age. The maximum difference in age was 4 days. Piglets introduced to the Rescue Decks were on average 4.2 days old (range across batches: 3–6 days) and weighed on average 2.1 kg (range: 1.6–3.1 kg). All 14 piglets in the two Rescue Decks served as focal piglets for behavioural observations.

During six of the seven batches, two litters (average litter size: 11.8 piglets, range: 5–14 piglets) were not manipulated and reared by their respective mothers in the farrowing pen (control treatment). In a given batch, seven piglets from each of the two litters (five piglets in the one litter that did not have at least seven piglets) were selected as focal animals for behavioural observations (seven male and seven female piglets balanced across litters). The weight of these focal piglets was matched to the weight of the piglets reared in the Rescue Decks considering both the average weight and the weight range. Solid feed (pre-starter and starter feed) for the piglets was provided daily on the rubber mat of the piglet box from about the sixth day onwards (range: 2–9 days) until weaning.

Piglets were removed from the Rescue Decks at an average age of 33.9 days (range: 31–36 days) and an average weight of 7.9 kg (range: 4.7–11.1 kg). One piglet died on day 14 after introduction to the Rescue Deck. Piglets weaned from the farrowing pens had an average age of 31.6 days (range: 22–37 days) and an average weight of 8.0 kg (range: 5.2–12.0 kg). None of the focal piglets reared by a sow died.

All procedures involving animal handling and treatment were approved by the Cantonal Veterinary Office Thurgau (Switzerland, permit no. F1/12).

2.2. Artificial piglet rearing system

The two Rescue Decks were placed in a separate compartment at the Agroscope's swine barn in Tänikon (Switzerland). They were installed on a frame approximately 1 m above the floor and consisted of a white plastic box (1.34 × 0.82 m; height: 0.54 m) with a transparent viewing window in the front. According to Swiss animal welfare legislation, one Rescue Deck provided space for 7 piglets up to 10 kg (available floor space per piglet: 0.15 m^2). The Rescue Decks were structured into a feeding/dunging area in the front part of the box and a lying area (0.69 × 0.82 m) in the rear part of the box. The two areas were separated by a transparent curtain made of plastic stripes. The lying area was covered by a white, non-transparent plastic lid that contained a hole for a 250-W infrared heat lamp. The slatted floor in the feeding/dunging area was made of plastic-coated, rhombic expanded metal, and had a maximum slot-width of 9 mm. The floor in the lying area was covered with a rubber mat, on which fresh bedding (chopped and sieved *Miscanthus giganteus* or dedusted wood shavings) was provided daily (approximately 70 g per day and Recue Deck). To avoid that the bedding material was shifted from the rubber mat to the slatted floor, a wooden block (2 cm high) was fixed on the ground separating the lying from the feeding/dunging area.

The milk system consisted of a storage bin, a ring line composed of plastic tubes, and two cups with a diameter of 11 cm per Rescue Deck. The cups were attached on the slatted floor in the front part of the feeding/dunging area near the transparent viewing window. Each cup had a nipple in the middle, which could be operated by the piglets by pushing it slightly to one side. Artificial milk ('Rescue Milk', Provimi B.V., Rotterdam, the Netherlands) was prepared fresh twice a day and was available ad libitum to the piglets. To familiarise piglets with the functionality and location of the milk cup system, they were trained to drink from the cups by dipping each piglet's snout 2–4 times into the cup during their first 2 days in the Rescue Deck. Due to the lack of space at the milk cups, it was not possible for all piglets to drink artificial milk simultaneously. The storage bin and the plastic tubes of the ring line were cleaned and disinfected once a week with a liquid alkaline detergent (Halapur MP, Halag Switzerland, Aadorf, Switzerland). The artificial milk was replaced by solid feed when the cumulative per-piglet-consumption of milk reached an average of 3.9 kg dry matter (range: 3.5–4.4 kg of dry matter per piglet). Piglets then had an average weight of 5.7 kg (range: 3.9–8.3 kg) and had spent on average 14.2 days (range: 13–16 days) in the Rescue Decks. Water was provided ad libitum in the feeding/dunging area from the third day onwards and offered in a third cup identical to the two milk cups in terms of shape and functionality. A feeder (Kane Creep Feeder KCF-9, Agro Weber GmbH, Lenggenwil, Switzerland; 24 × 14 cm, height: 33 cm) was mounted on the wall of the lying area from on average the sixth day (range: 4–8 days) onwards to provide fresh solid feed (pre-starter and starter feed) twice a day.

2.3. Behavioural observations

Behaviour of all focal piglets was videotaped and scored on each observation day by continuous focal observation in the periods from 05:00 to 10:15 and from 13:00 to 18:15. Artificially raised piglets of batches 1–6 were observed on day 4 after introduction to the Rescue Decks, those of batches 4–7 on day 11, and those of batches 1–7 on day 18. The behaviour of focal piglets reared by the sow (batches 1–6) was recorded on days 4 and 18 after piglets of a given batch had been transferred to the Rescue Decks. Observation day 11 was added for piglets raised artificially from batch 4 onwards to better differentiate the effects of the age of the piglets and the change in diet on behaviour. As a consequence, artificially raised piglets were observed on days 4 and 11 when they were still provided with artificial milk and on day 18 when they were fed solely on solid feed. Due to special management events and technical problems

Table 1
Definitions of evaluated behavioural patterns.

Behavioural pattern	Definition
Belly nosing	Repetitive, rhythmic up-and-down movement with the snout (Fraser, 1978) on the body of a pen mate, especially performed on the skin behind the ear and on the abdomen between the front and the hind limbs
Manipulation of a pen mate	Nosing, nibbling, or sucking on the body of a pen mate (Torrey and Widowski, 2006)
Aggressive behaviour	A single short attacking, biting, pushing, and head thrusting directed at a pen mate (McGlone, 1986)
Play-fighting	Scampering, hopping, head tossing, pivoting, shaking objects (Newberry et al., 1988), running around with rapid changes in direction (Camerlink and Turner, 2013), running by throwing themselves on the floor or against a pen mate (Worsaae and Schmidt, 1980), or a repeated or longer lasting attacking, biting, pushing, head thrusting or chasing of a pen mate (McGlone, 1986); play behaviour often led suddenly to fighting encounters or to a continuous change between play behaviour and (playful) fighting within a short period of time
Resting	Lying laterally or ventrally (Kelly et al., 2000)

(e.g. medical treatment of piglets' eyes, delayed provision of solid feed), video recording was postponed as an exception for up to 2 days to ensure that the piglets were undisturbed for at least 48 h before behavioural observation.

To facilitate videotaping, lights in the farrowing room, in the piglet box (Everlight MR 16 LED-lamp warm white 5 W 50°, EVERLIGHT Electronics Europe GmbH, Karlsruhe, Germany) of the farrowing pen, and in the room where the Rescue Decks were located remained switched on during the days of video recording. To videotape piglet behaviour in a Rescue Deck, a video camera was mounted approximately 1.5 m above the feeding/dunging area, and a mini-dome camera was attached above the lying area directly under the lid. In the farrowing room, one video camera per farrowing pen was mounted approximately 2.5 m above the floor, and mini-dome cameras were fixed directly under the lids of the piglet boxes. One day before the focal piglets were videotaped, they were marked individually by different blue patterns on their backs.

For behavioural scoring, only one piglet was chosen at any time and observed continuously for 15 min in a previously determined random order. Each artificially raised piglet and each focal piglet reared by the sow were thus scored three times in the morning sessions and three times in the afternoon sessions. The recordings on days 4, 11 and 18 of batches 1–6 were evaluated by one observer, whereas the recordings on days 11 and 18 of batch 7 were analysed by a second observer who had undergone previous training. Definitions of the evaluated behavioural patterns are listed in Table 1.

2.4. Statistical analysis

Durations and counts of occurrences of specific behavioural patterns were calculated across the 90 min of observation per animal and day and were analysed by using linear mixed-effects models in R (version 3.0.2; R Core Team, 2013) with the lmer method from the lme4 package (Bates et al., 2014). For the statistical analyses of these data, we were faced with two issues. First, the durations of most behaviour patterns were limited at low durations, that is, towards zero but some (specifically resting) were also limited by the maximum observation time. Second, the total observation period of 90 min per animal and day varied by up to 45 s due to technical aspects of the scoring software used. To account for these aspects and make all observations fully comparable, we calculated the proportion of the observation time and the frequency (counts of occurrences divided by the observation time) to reflect duration and occurrence of the specific behavioural patterns, respectively. Model assumptions were checked based on a graphical analysis of residuals in respect to the normal distribution of errors and random effects as well as the homoscedasticity of the errors. To satisfy these assumptions, the outcome variables needed to be transformed and we used the logit and log transformation for the proportion of time and the frequency of specific behavioural patterns, respectively (Table 2). For the proportion of time, we could have used the arc-sinus-square-root transformation but we preferred the logit transformation because the natural base to the power of the estimated parameters can be interpreted as odds-ratios. For both transformations, zeroes were replaced by a value 10% smaller than the lowest recorded data value larger than zero and ones would have been replaced analogously for the logit-transformation if they had occurred. If at all, this procedure led to a data set that was slightly more conservative than the raw data set by making these extreme observations somewhat less extreme. Such a replacement is biologically meaningful in the sense that the subjects' motivation for performing a specific behaviour is unlikely ever nil even if the behaviour was not observed. Using the lowest recorded data value estimated the detection threshold for this behaviour, and zeros are replaced by this detection threshold.

Random effects were the animal nested in pen nested in batch. Fixed effects were treatment (factor with two levels: artificially raised or reared by the sow), day (coded as a continuous variable with possible values 4, 11 and 18) and their interaction. This model assumed a linear pattern across days on the transformed scale of the outcome variable, that is, a continuous increase or decrease from day 4 to 11 to 18. Whether this assumption was justified was tested with a further fixed effect, an indicator for non-linearity. This indicator for non-linearity was set to one for day 11 of the artificially raised piglets and otherwise to zero. Significance of this indicator of non-linearity then indicated that day 11 in the artificially raised piglets deviated from the linear pattern, whereas non-significance suggested that the pattern could not be differentiated statistically from a linear one. This maximum model (treatment plus day, their interaction and the indicator for non-linearity) corresponded to a model that would have used day as a factor

Table 2
Outcome variables, their transformation, model chosen in a step-wise backwards selection approach, and test statistics (χ^2) and P-values for the fixed effects.

Outcome variable	Parameter	Transformation	Best model[a]	Treatment	Day	Treatment x day	Indicator for non-linearity
Belly nosing	Duration	Logit	t × d			$P<0.001$; $\chi^2_1=40.53$	$P=0.37$; $\chi^2_1=0.81$
Belly nosing	Frequency	Log	t × d			$P<0.001$; $\chi^2_1=33.65$	$P=0.66$; $\chi^2_1=0.19$
Manipulation of a pen mate	Duration	Logit	t + d	$P<0.001$; $\chi^2_1=22.73$	$P=0.91$; $\chi^2_1=0.01$		$P=0.96$; $\chi^2_1=0.003$
Manipulation of a pen mate	Frequency	Log	t + d	$P<0.001$; $\chi^2_1=23.24$	$P=0.01$; $\chi^2_1=6.62$		$P=0.76$; $\chi^2_1=0.09$
Play-fighting	Duration	Logit	t × d			$P=0.02$; $\chi^2_1=5.26$	$P=0.14$; $\chi^2_1=2.15$
Aggressive behaviour	Frequency	Log	t + d + inl	$P<0.001$; $\chi^2_1=20.96$	$P=0.42$; $\chi^2_1=0.66$		$P=0.004$; $\chi^2_1=8.16$
Resting	Duration	Logit	t × d			$P<0.001$; $\chi^2_1=20.53$	$P=0.69$; $\chi^2_1=0.16$
Average resting bout length	Duration	Logit	t + d	$P<0.001$; $\chi^2_1=16.61$	$P=0.64$; $\chi^2_1=0.22$		$P=0.051$; $\chi^2_1=3.82$

[a] t = treatment, d = day, inl = indicator for non-linearity of the day effect.

and was reduced in a step-wise backwards approach using likelihood-ratio tests between nested models differing in their fixed effects. The main effects of treatment and day were always retained in the final model. Only statistically significant influences of fixed effects are mentioned in the results.

3. Results

Belly nosing was hardly ever observed in piglets reared by the sow, with the exception of one piglet which performed belly nosing twice within 25 s on day 18. With piglets raised artificially, the duration as well as the frequency of belly nosing increased monotonously between days 4 and 18 (Fig. 1a and b; Table 2).

Throughout the observation period, artificially raised piglets spent more time manipulating a pen mate than piglets reared by the sow, and the level was constant from days 4 to 18 for both treatment groups (Fig. 1c; Table 2). With regard to the frequency of manipulation of a pen mate, a higher level was noticed in artificially raised piglets than in piglets reared by the sow, and a monotonous decline from days 4 to 18 was observed for both treatment groups (Fig. 1d; Table 2).

Piglets reared by the sow displayed play-fighting longer than artificially raised piglets, and the decrease in duration from days 4 to 18 was stronger in piglets raised artificially (Fig. 1e; Table 2).

Aggressive behaviour was shown more frequently by artificially raised piglets than by piglets reared by the sow. In piglets raised artificially, frequency of aggressive behaviour increased from days 4 to 11 and decreased from days 11 to 18 (Fig. 1f; Table 2).

Duration of resting increased from days 4 to 18 in the piglets reared by the sow and decreased monotonously between days 4 and 18 in artificially raised piglets (Fig. 1g; Table 2). Throughout the observation period, average resting bout length was longer in piglets reared by the sow than in artificially raised piglets (Fig. 1h; Table 2).

4. Discussion

The current study compared two systems for raising piglets, an artificial rearing system in which piglets were removed from their mothers early and when piglets remained with their mothers. Given the comparison of two complete systems and some decisions in our experimental design, many variables differed between the two treatment groups and were therefore confounded. These aspects included age of piglets at separation from the mother, quality of the milk, age of piglets at weaning from milk, group size, space allowance (and density), mixing with piglets from other litters, quality of bedding material, and the room where the two rearing systems were set-up on the farm. That is, all differences found and discussed below can potentially be caused by any of these differences. For the practical purpose of the current assessment of the artificial rearing system as a whole, the specific causal effect is less relevant and therefore an assessment of the artificial rearing system in comparison to be raised by the mother can be made. For the understanding of the differences in piglet

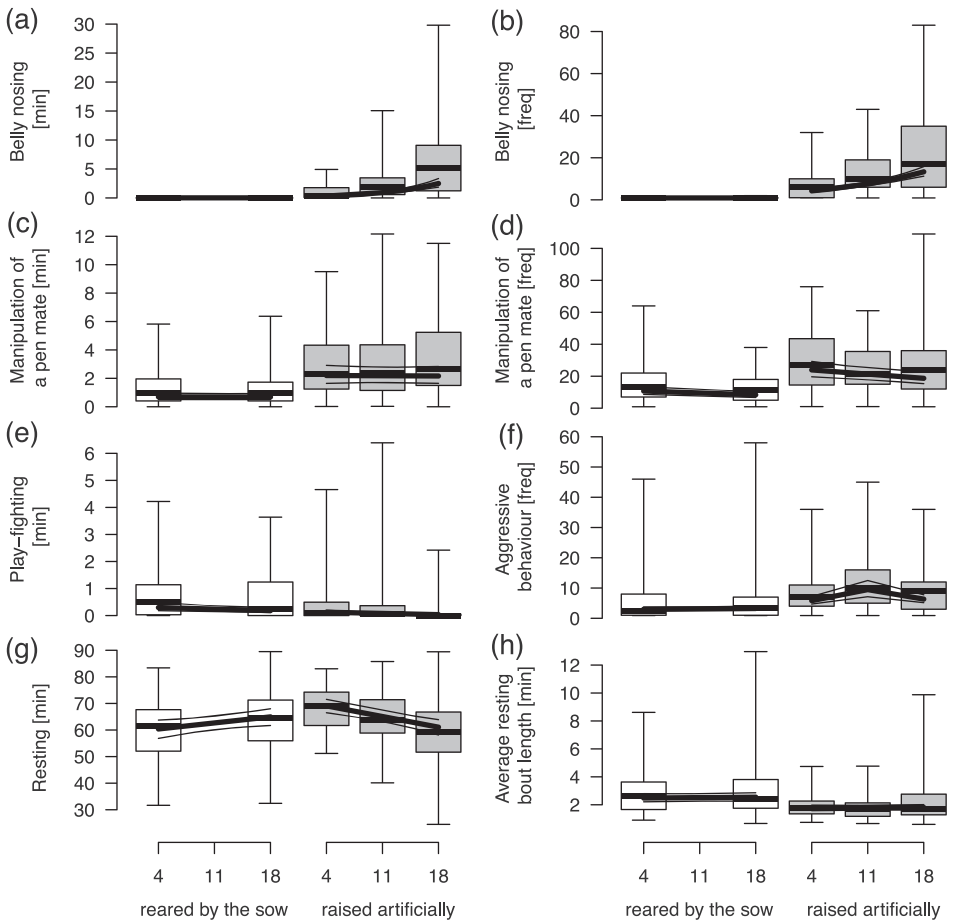

Fig. 1. Duration of belly nosing (a), frequency of belly nosing (b), duration of manipulation of a pen mate (c), frequency of manipulation of a pen mate (d), duration of play-fighting (e), frequency of aggressive behaviour (f), duration of resting (g), and average resting bout length (h) per piglet per 90 min on days 4, 11, and 18 when piglets were either reared by the sow or raised artificially. On days 4 and 11, all piglets were provided with milk, whereas on day 18 piglets with the sow still had her milk available but piglets raised artificially were fed with solid feed only. Box-and-whisker plots: boxes = 1st and 3rd quartile, thick lines = median, whiskers = range from minimum to maximum value. Thick trend-lines = model estimation, thin trend-lines = 95% credible intervals.

behaviour and with a view on potential improvements of such a system, causal understanding of the behavioural differences is important and previous investigations allow for well-informed guesses as to which differences in the systems lead to the behavioural differences observed.

In the present experiment, artificially raised piglets regularly showed belly nosing, whereas piglets reared by the sow hardly ever performed this abnormal behaviour. Moreover, the duration as well as the frequency of belly nosing increased monotonously in artificially raised piglets between days 4 and 18 after introduction to the Rescue Decks. These observations are in line with the results of previous studies showing that belly nosing almost never occurs before weaning or is observed on a considerably higher level in piglets weaned than in those that remain with the sow (van Putten and Dammers, 1976; Fraser, 1978; Worsaae and Schmidt, 1980; Orgeur et al., 2001). In agreement with observations made in the present study, belly nosing is considered to be similar to suckling behaviour (Fraser, 1978; Weary et al., 1999) and in particular to the vigorous massaging movements that piglets perform at the sow's udder before and after milk ejection (Worobec et al., 1999; Li and Gonyou, 2002). Lacking an adequate object to massage, weaned piglets redirect this behaviour pattern to the body of pen mates (van Putten and Dammers, 1976; Dybkjaer, 1992), probably because the mates' soft and warm body surface is similar to the sow's udder and therefore attractive to the piglets (Welch and Baxter, 1986).

Manipulation of a pen mate with behaviour patterns (nosing, nibbling, sucking) other than belly nosing was performed by artificially raised piglets and piglets reared by the sow in the present study. However, such behaviour occurred for longer time periods and at a higher rate in artificially raised piglets. As sucking was included in 'manipulation of a pen mate', it is likely that artificially raised piglets showed more manipulation because they redirected sucking behaviour at pen mates (qualitative observations; van Putten and Dammers, 1976). Drinking artificial milk from a milk cup is also a motor pattern that differs much from sucking milk at the sow's teats, as reported by Gardner (2000).

In the present study, artificially raised piglets were provided with a relatively small amount of wood shavings or *M. giganteus* as bedding material in the lying area, whereas piglets reared by the sow had straw in larger quantity offered in the nesting area. It is thus possible that the lower quality or quantity of bedding material in the artificial piglet rearing system induced less exploratory and manipulative behaviour in artificially raised piglets compared with piglets reared by the sow, and that the former redirected such behaviour (nosing, nibbling) to other piglets resulting in increased levels of manipulation of pen mates. In line with this interpretation, Dybkjaer (1992) and Bøe (1993) reported that piglets weaned at 4 weeks of age and raised in barren housing conditions manipulated pen mates more frequently by nibbling, sniffing, rooting, or chewing than piglets weaned at the same age but housed in enriched pens with bedding material, such as straw.

In addition to the impact of bedding material, the difference in space allowance between the two rearing systems compared in the present study could have had an effect on the level of manipulation of a pen mate. Space allowance for artificially raised piglets was 0.15 m^2 per piglet, whereas piglets reared by the sow in a farrowing pen were offered 7.36 m^2 for 5–14 piglets (and their mother). Gardner et al. (2001) found that piglets weaned at the age of 12–14 days and kept at high density (0.15 m^2 per piglet) showed more piglet-directed nosing compared with piglets housed at a lower density (0.4 m^2 per piglet). In conditions with low space allowance, spatial proximity of neighbouring piglets may enhance manipulation of pen mates and manipulated piglets may find it difficult to escape such manipulation due to spatial conditions (Gardner et al., 2001).

In the present study, piglets reared by the sow displayed play-fighting longer than artificially raised piglets, and the decrease in duration from day 4 to 18 was stronger in piglets raised artificially. This pattern is likely caused by the difference in space allowance between the two compared rearing systems. Accordingly, Worsaae and Schmidt (1980) and Dybkjaer (1992) reported that a reduction in space allowance for piglets weaned at the age of 3–4 weeks resulted in a decrease in play behaviour, and Chaloupkova et al. (2007) found that pre-weaned piglets showed a higher level of locomotor and social play when offered more space. However, in these studies as well as in the present study, space allowance was confounded with environmental enrichment, which could also have an effect on the occurrence of play behaviour.

Artificially raised piglets in the present study showed more aggressive behaviour than piglets reared by the sow, and the frequency of aggressive interactions increased in the former from day 4 to 11 and decreased from day 11 to 18. This pattern may be due to the lack of space at the milk cups in the artificial piglet rearing system in combination with increasing size of the piglets. On day 11, at most 2 piglets had access to one milk cup at the same time, and a maximum of 4 piglets could drink at the same time from the two milk cups available. On day 18, artificial milk had been replaced by solid feed in the Rescue Decks, and piglets ate less often simultaneously. The high frequency of aggressive behaviour shown by artificially raised piglets could also be linked to the high levels of belly nosing and manipulation of pen mates observed in these piglets. Similarly, Fraser (1978) reported that piglets occasionally bit at pen mates in response to being belly nosed. The two rearing environments compared in the present study also differed in group composition. Piglets reared by the sow were reared as intact litters, whereas artificially raised piglets stemmed from two to four litters and were mixed. This may have had an effect on aggression level, as a change in group composition at weaning was found to result in an increase in agonistic interactions (Weary et al., 2008; Hötzel et al., 2011; Colson et al., 2012). Contrary to this, Jarvis et al. (2008) reported that aggression after weaning also occurs in piglets that are not mixed. They hypothesised that, even without social mixing, separation from the sow may result in changes in the piglets' social relationships and hierarchy.

In artificially raised piglets, duration of resting decreased between days 4 and 18, whereas this duration increased from day 4 to 18 in piglets reared by the sow. Moreover, average resting bout length was shorter in artificially raised piglets than in piglets reared by the sow throughout the observation period. This pattern could be due to the low space allowance provided to the artificially raised piglets. Accordingly, Gardner et al. (2001) found that piglets weaned at 12–14 days of age rested longer when kept at a low density (0.4 m^2 per piglet) compared with piglets housed at a higher density (0.15 m^2 per piglet). The results of the present study suggest that lying behaviour in artificially raised piglets was increasingly affected by space allowance as they grew in size from day 4 to 18. In addition to space allowance, changeover of artificial milk to solid feed could also affect resting behaviour in piglets. However, in the present study, duration of resting decreased monotonously in artificially raised piglets between days 4 and 18 and did not change markedly between days 11 and 18 when artificial milk was replaced by solid feed.

The piglets in the two rearing conditions were kept in separate compartments for reasons of hygiene. As a consequence, location was confounded with treatment. However, it seems rather unlikely that the differences between the two rooms led to the differences in behaviour. For example, even if the barn-climate was slightly different in the two rooms, no large differences in respect to belly nosing and manipulation of other pen mates would be expected. In line with this, differences in behaviour similar to those reported here were found in piglets raised in another artificial rearing system, the so-called "Nursery", compared to piglets reared by the sow in a loose farrowing pen (Rzezniczek et al., 2014).

To understand the causation of the behavioural differences between the two systems that we observed and if one wanted to develop the artificial rearing system further in respect to animal welfare, additional experiments would be necessary. The starting points for such experiments could be seen in the different interpretations as suggested above. For example, if belly nosing is to be reduced, the influence of the specific way of milk intake (suckler versus cup) or the availability of a stimulus eliciting massaging behaviour (such as an artificial udder) could provide a starting point for further research. If one wanted to increase play behaviour and reduce interruptions of lying, experiments with increasing space allowance should be conducted first.

Finally, if aggression was to be reduced, an experiment could be conducted that increases the number of piglets that can feed simultaneously.

5. Conclusions

The results of the present study indicate that the welfare of piglets removed from the sow at the age of 3–6 days and raised in an artificial piglet rearing system is impaired. Compared with piglets reared by the sow in a loose farrowing pen, artificially raised piglets showed high and increasing levels of belly nosing, more manipulation of pen mates, more aggressive behaviour, and less play-fighting and resting behaviour than piglets reared by the sow in a loose farrowing pen. Whereas the occurrence of belly nosing is likely to be linked to early separation from the sow, with piglets redirecting massaging behaviour to their pen mates, other differences in behaviour may be due to the small space allowance in the tested artificial rearing system. As piglets grew in this system, they were limited in play-fighting, their resting behaviour was disturbed, and they directed more manipulative and aggressive behaviour at the pen mates. As a consequence, more research is needed to improve the housing conditions of piglets raised in commercially available artificial piglet rearing systems with regard to animal welfare.

Conflict of interest

We herewith confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

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