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Can we improve maternal care in sows? Maternal behavioral traits important for piglet survival in loose-housed sow herds[1]

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ABSTRACT: The primary objective of this survey was to investigate the relationship between qualitative maternal behavioral scores (nest building activities, sow communication, and sow carefulness), piglet mortality, and the number of weaned piglets on commercial farms with loose-housed lactating (Norsvin Landrace × Yorkshire) sows. Second, the impact of these scores on productivity compared with the physical condition of sows (movement disorders, body condition, and shoulder lesions) was assessed. Data on maternal care behaviors and physical condition were collected on 895 sows from 45 commercial farms. Farmers scored sows on their physical condition (movement disorders [MD], BCS, and shoulder lesions [SL]) and qualitative maternal care behaviors (nest building activities [NEST] prior to farrowing and sow communication [COM] and sow carefulness [CARE] after farrowing, while sows were standing and moving and just before lying down). There was a low positive correlation between NEST and COM ($r = 0.10$, $P = 0.026$) and between NEST and CARE ($r = 0.15$, $P = 0.010$) but a high positive correlation between COM and CARE ($r = 0.57$, $P < 0.001$). Higher COM and CARE were associated with lower piglet mortality ($P < 0.001$ and $P = 0.013$, respectively), and a greater number of weaned piglets was associated with higher scores for NEST ($P = 0.009$), COM ($P < 0.001$), and CARE ($P = 0.009$). Maternal care behavior had a greater impact on piglet mortality and the number of weaned piglets than sow physical condition (MD, BCS, and SL). We tested 7 different models (combinations of behavioral scores) and compared their relative predictive accuracies using Akaike information criteria. The model including COM and CARE had the best predictive accuracy for piglet mortality/weaned piglets. There was between-sow variation in maternal care behaviors (COM and CARE), and both were unaffected by litter size. Because these behaviors were also easy to score for the farmers, combining COM and CARE has the greatest potential to be tested in nucleus herds for calculation of genetic variation and heritability and should be taken into account in future breeding programs for sows.

Key words: nest building, piglet mortality, sow carefulness, sow communication, sow physical condition

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INTRODUCTION

Although modern maternal sow breeding programs have resulted in more piglets weaned (Ocepek et al., 2017), piglet mortality is still a major welfare and economic issue because approximately 20% of piglets born are dead or eventually died before weaning (Ocepek et al., 2016a). Piglet survival until weaning depends on interacting factors such as the physical environment (Andersen et al., 2007), management routines (Andersen et al., 2007; Rosvold et al., 2017), piglet viability (Pedersen et al., 2011), and maternal behavior (Andersen et al., 2005; Ocepek and Andersen, 2017). Promoting maternal care behaviors in sows kept loose during farrowing and lactation can result in fewer piglet deaths and improve the welfare of pigs and, thus, contribute to more sustainable breeding.

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Despite attempts to promote maternal care traits (Grandinson et al., 2003; Løvendahl et al., 2005; Vangen et al., 2005), there are methodological challenges with accurately measuring traits. A recent experimental study documented a clear relationship between simple qualitative scorings of maternal care behaviors (sow nest building and sow communication and carefulness) important for piglet survival (Ocepek and Andersen, 2017). To be useful under commercial conditions, these scores need to be simple and practical for farmers to be able to assess those traits on the farm.

The primary objective of this survey was to investigate the relationship between qualitative maternal behavioral scores (nest building activities, sow communication, and sow carefulness) and piglet mortality and the number of weaned piglets on commercial farms with loose-housed lactating (Norsvin Landrace × Yorkshire) sows. Second, the impact of these scores on productivity compared with the physical condition of sows (movement disorders, body condition, and shoulder lesions) was assessed.

MATERIAL AND METHODS

The present experiment was conducted in accordance with the laws and regulations controlling experiments and procedures on live animals in Norway and was approved by the Norwegian Animal Research Authority, following the Norwegian Regulation on Animal Experimentation Act of 1996 (Nara, 2017).

Farm Selection and Study Design

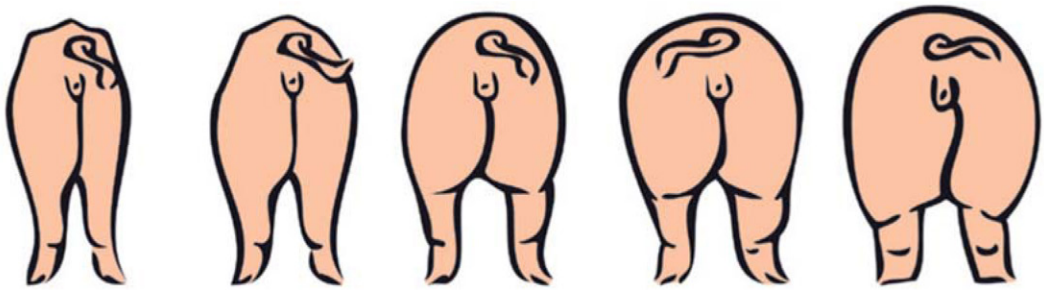
Forty-five commercial pig farms were visited, and all met the following criteria: 1) had loose-housed lactating Norsvin Landrace × Swedish Yorkshire sows, 2) were located within the 3 major pig production regions in Norway (16 in the east, 12 in the west, and 17 in the middle), 3) differed in size (14 small farms, which produced 30–110 litters per year; 18 medium farms, which produced 110–200 litters per year; and 13 large farms, which produced 200+ litters per year), and 4) kept farm production records in Ingris (2017; The National Efficiency Control Database, administrated by Animalia [Norwegian Meat and Poultry Research Centre, Oslo, Norway] and Norsvin [Norwegian Pig Breeders Association, Hamar, Norway]). To investigate the importance of sow behavioral and physical characteristics, an on-farm registration form was designed. The registration form, together with instructions (see On-Farm Registration below; see farm instructions in on-line supplemented material), was sent to the farmers approximately 1 mo before the onset of the study, which was followed up with a phone call (to answer all question regarding the scores) and farm visitation by one of the trained researchers (M. Ocepek or E. M. Rosvold). During the visit, additional information regarding environment and management routines on the farm was collected. The completed registration forms with behavioral and physical scores for each sow from one batch on the farm was sent to us, whereas the following production records for the same sows were collected from the Ingris database: parity number, number of live-born piglets, number of piglets that died after farrowing but before weaning, and number of weaned piglets (defined as number of the sow's own live-born piglets plus the number of piglets fostered on minus the number of piglets fostered off and minus the number of piglets that died after farrowing but before weaning).

On-Farm Registration

The on-farm registration form included qualitative behavioral scores developed by Ocepek and Andersen (2017) and physical scores as tested by Ocepek et al. (2016a).

Sow – Physical Scores. Sow physical condition scores (movement disorder [**MD**], BCS, and shoulder lesions [**SL**]) were assessed while the sows were being moved the from the gestation unit to the farrowing unit. Movement disorders were scored using a scale from 1 to 3 (1 = normal, without visible movement problems; 2 = marked MD, walks slowly or limps in a stiff way; and 3 = severe movement problems, can hardly get up from a lying position or walk; Ocepek et al., 2016a). Body condition score was assessed using a grading scale from 1 to 5 and half points were used (Fig. 1). Presence of SL was assessed using a 5-category scale. Score 0 was used when the shoulder region was intact, with healthy skin and without reddening or swelling. If SL were seen, scores from 1 to 4 were used (Fig. 2).

Sow – Behavioral Scores. The nest building activities (**NEST**) score was assessed after sows began to display preparation signs of farrowing (restless behavior, nesting behavior, and/or teats ejecting milk at hand milking) on one arbitrary occasion (2–5 min of observation) during morning or afternoon feeding within the last 24 h before expected parturition. The NEST score included rooting (nosing in the nest building material on the floor), pawing (leg in the nest building material on the floor), carrying nest building material, and chewing nest building material while the sow was active (standing or moving around) using a scale from 1 to 3, as presented in Table 1. Sow communication (**COM**; sniffing, grunting, and nudging) and sow carefulness (**CARE**) was assessed on one arbitrary occasion (2–5 min of observation), immediately after morning or afternoon feeding on d 1 or 2 postpartum while sows were active (changed position or



Score	1	1.5	2	2.5	3	3.5	4.0	4.5	5.0
Definition	Very thin, with hips and backbone very prominent without fat covering hips and backbone		Thin, hip bones and backbone are easily felt without any pressure on the palms		Normal-good, it takes firm palm pressure to feel the hip bones and backbone		Fat; impossible to feel the bones at all, even when pressed with palm		Very fat, so fat that it is impossible to feel the hip bones and backbone even by pushing down with a single finger

Figure 1. Body condition scores (Animalia, 2014).

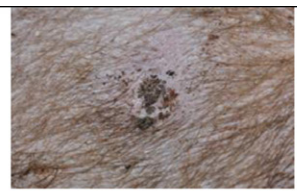
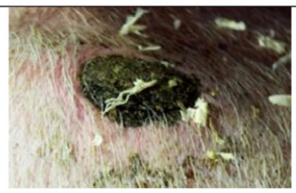
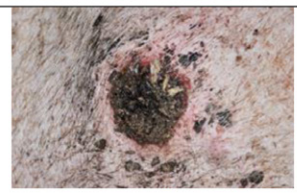
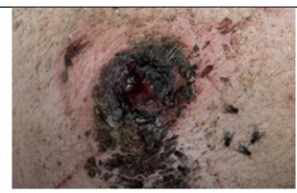
Score 1		
Initial stage, mild lesions of the skin, including reddening or swelling or minor nonbleeding patches/wounds (diameter < 2 cm)		
Score 2		
Moderate skin lesions, the wound includes the entire skin thickness and causes bleeding; crusts are common (diameter 2 - 3 cm), and the amount of granulation tissue is very moderate		
Score 3		
Serious lesions, these lesions include subcutaneous tissue, but not bone; swelling around the wound and production of granulation tissue are common (diameter 3 - 5 cm)		
Score 4		
Very serious lesions, serious injury involving the scapula bone. The tissue around the lesion is thickened and often adherent to the underlying bone, granulation tissue is common. The wound has commonly a diameter of 5 cm or more		

Figure 2. Shoulder lesion scores (Animalia, 2014).

Table 1. Scale definition of qualitative behavioral scores (reproduced from Ocepek and Andersen [2017])

Behavioral scores[1]	Definition of scale values
NEST	1 = No nest building events observed
	2 = Less than 50% of the active time spent nest building
	3 = More than 50% of the active time spent nest building
COM	1 = No events with communication, when the sow change position or move around
	2 = The sow communicates less than 50% of the event when she changes position or move around
	3 = The sow communicates more than 50% of the event when she changes position or move around
	4 = The sow communicates every event she changes position or move around
CARE	1 = No events when sow is observed showing attentive, careful, and protective behaviors
	2 = The sow is attentive, careful, and protective less than 50% of the events when she changes position or move around
	3 = The sow is attentive, careful, and protective more than 50% of the events when she changes position or move around
	4 = The sow is attentive, careful, and protective every time she changes position or move around

[1]NEST = nest building activities; COM = sow communication; CARE = sow carefulness.

moved around and at the moment the sow was about to lie down). Both scores, COM and CARE, were assessed on a scale from 1 to 4, as presented in Table 1.

Housing and Management Routines

Housing. According to the Norwegian animal welfare regulations, gestation stalls and farrowing crates are banned (Lovdata, 2017). During pregnancy, all sows must be kept in group-housing systems from 4 wk after service. From d 3 before expected parturition, sows shall have access to nest building material. During farrowing and lactation, sows must be kept loose in a farrowing pen larger than 6.0 m^2 with a width of more than 1.8 m, allowing the sow to turn around. Plenty of the litter should be on the pen floor. Furthermore, the farrowing pen must be designed in a way that provides sufficient space for the sows during farrowing (and for farrowing assistance, if needed) and a separate microclimate for the piglets that is inaccessible to the sow. Exceptions regarding confinement can be made for restless or aggressive sows but only for 1 wk (from parturition until the seventh day afterward) in crates longer than 2.0 m with a width of 0.7 to 0.8 m, depending on the sow's size.

The mean size of the farrowing pens in the 45 farms was 7.5 ± 0.1 m2 (range 6.0–10.5 m2), with a mean width of 2.3 ± 0.0 m (range 1.9–3.4 m), and none of the sows were crated at any time. Each sow was, on average, provisioned with 2.2 ± 0.32 kg (range 0.1–10 kg) of nest building material.

Management Routines. The variation in the management routines among the farms could be divided into 4 groups reflecting increasing effort from the farmer, as published by Rosvold et al. (2017). The variation in the management routines in the present study are representative for Norwegian commercial herds.

Collected Data

The mean number of sows per farm in a farrowing batch was 20.0 ± 0.9 (range 10–31), and sow parity ranged from 1 to 9, with 33.9% of the sows in the first, 23.3% in the second, 18.7% in the third, 12.5% in the fourth, 7.1% in the fifth, 2.3 in the sixth, 1.6% in the seventh, 0.3% in the eighth, and 0.3% in the ninth parity.

The data contained information on 895 sows, out of which there were 20 sows without BCS, 17 without MD scores, 18 without SL scores, 15 without NEST scores, and 3 without COM scores.

To facilitate subsequent calculations, BCS scores were transformed into values from 1 to 3: thin (1.0–2.5), normal (3.0–3.5), and fat (4.0–5.0). Around 13% percent of the sows were thin, 63% of the sows were categorized as normal, and 24% of the sows were classified as fat. Approximatively 93% of the sows had no signs of MD, 6% were slower (limping, score 2), and less than 1% had severe movement problems (score 3). Furthermore, around 93% of the sows had healthy skin without SL, more than 6% were classified with initial shoulder injuries, and less than 1% with moderate skin lesions (score 2) as well as serious SL (score 3). As there were very few higher scores for MD and SL, both traits were categorized into 2 classes (sows without MD and/or SL = class 1 and sows with MD and/or SL = class 2).

Statistical Analysis

Descriptive statistics were presented as the arithmetic mean and SE. Statistical analyses were performed using SAS 9.4 statistical software program (SAS Inst. Inc., Cary, NC).

The effects of physical condition (MD, BCS, and SL) as fixed effects (class variables) on behavioral scores (NEST, COM, and CARE) were analyzed using the GLIMMIX procedure (multinomial distribution).

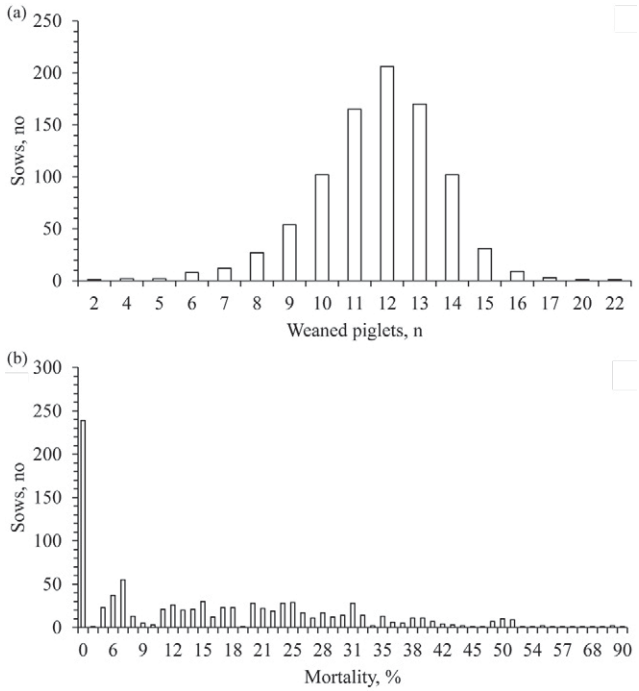


Figure 3. Distributions of sows in relation to (a) the number of weaned piglets and (b) piglet mortality.

Parity and litter size were included as continuous variables. Farm was specified as a random effect.

Polychoric correlation coefficients were used when testing the relationships between sow behavioral scores (NEST, COM, and CARE).

The effect of behavioral (NEST, COM, and CARE) and physical (MD, BCS, and SL) scores as fixed class variables on piglet mortality and the number of weaned piglets was analyzed using a mixed model (PROC MIXED). Farm (class variable) and parity and litter size (continuous variables) were included in the model. Sow nested within the farm was specified as a random effect.

To find the best combination of behavioral scores (7 combinations of defined scores), the model with the best relative predictive accuracy for piglet mortality/weaned piglets was determined using the Akaike information criterion (**AIC**). The AIC values were transformed to Akaike weights to provide the relative probability of each model having the best predictive accuracy.

RESULTS

Descriptive Data

The mean number of piglets at birth was 14.1 ± 0.1 (range 3–23) and at weaning was 11.6 ± 0.1 (Fig. 3a), whereas the overall mean postnatal mortality was 16.3 ± 0.5% (Fig. 3b).

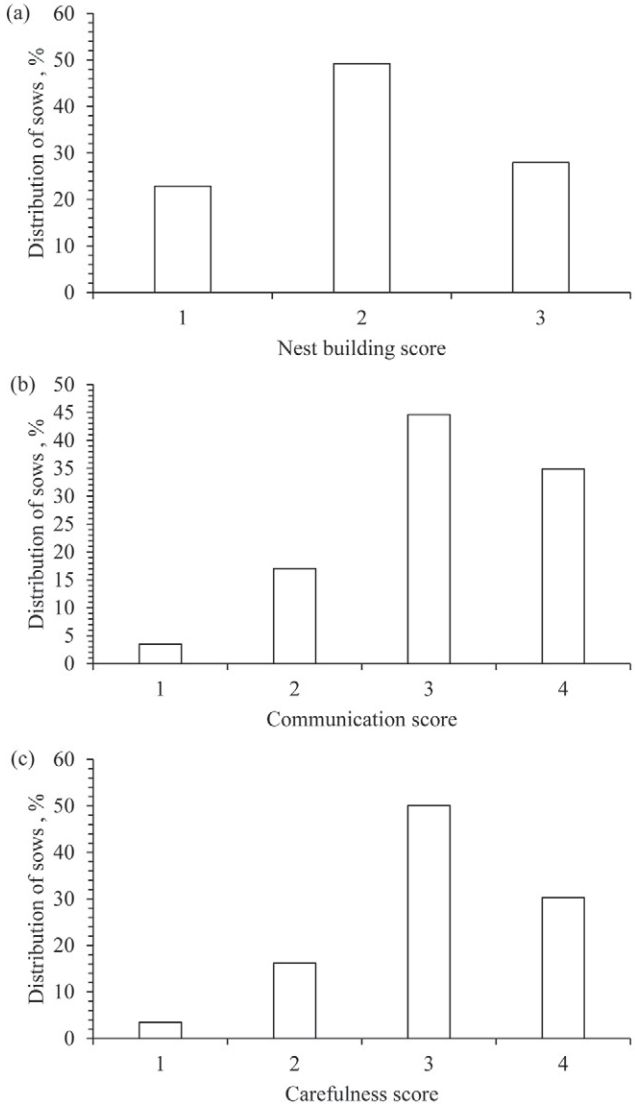


Figure 4. Distributions of sows in relation to behavioral scores: (a) nest building, (b) sow communication to piglets, and (c) sow carefulness toward piglets.

Sow Behavior

Nest Building Behavior Score. There was between-sow variation in NEST (Fig. 4a). There was no significant effect of parity or litter size on NEST (Table 2). Sows with MD had a lower NEST score than sows without (Table 2). Sows with normal BCS had higher NEST scores compared with thin or fat sows (Table 2). The NEST score was unaffected by SL (Table 2).

Sow Communication Score. Between-sow variation in COM is presented in Fig. 4b. There was a negative relationship between parity and COM (Table 2; Fig. 5a). Sow communication was not significantly affected by litter size (Table 2). Sows with MD had lower COM scores than sows without (Table 2). Sow communication was not significantly affected by BCS or SL (Table 2).

Table 2. Influence of fixed effects on qualitative behavioral scores

Sow behavioral score[1]	Parity		Litter size		MD[2]		BCS		SL[3]	
	$F_{1, 805}$	*P*-value	$F_{1, 805}$	*P*-value	$F_{1, 805}$	*P*-value	$F_{2, 805}$	*P*-value	$F_{1, 805}$	*P*-value
NEST	0.2	ns[4]	0.0	ns	6.3	0.012	3.8	0.022	0.2	ns
COM	14.3	<0.001	0.6	ns	3.7	0.050	1.5	ns	2.0	ns
CARE	15.7	<0.001	1.5	ns	7.7	0.006	0.0	ns	0.3	ns

[1]NEST = nest building activities; COM = sow communication; CARE = sow carefulness.

[2]MD = movement disorder.

[3]SL = shoulder lesions.

[4]ns = not significant.

Sow Carefulness Score. Between-sow variation in CARE is presented in Fig. 4c. There was a negative relationship between parity and CARE (Table 2; Fig. 5b). Sow carefulness was not significantly affected by litter size (Table 2). Sows with MD had lower CARE scores than sows without (Table 2). Sow carefulness was not significantly affected by BCS or SL (Table 2).

Interrelationship between Behavioral Scores. There was a low positive correlation between NEST and COM ($r = 0.10$, $P = 0.026$) and between NEST and CARE ($r = 0.15$, $P = 0.010$) and a high positive correlation between COM and CARE ($r = 0.57$, $P < 0.001$).

Production Parameters

Postnatal Mortality. There was no significant effect of NEST on postnatal mortality (Table 3; Fig. 6a). Sows with higher COM scores had lower postnatal mortality (Table 3; Fig. 6b). The higher the CARE score, the lower the postnatal mortality (Table 3; Fig. 6c). There was no significant effect of parity on postnatal mortality (Table 3). Mortality significantly increased in larger litters (Table 3; Fig. 7). Postnatal mortality was not significantly affected by sow physical condition (MD, BCS, and SL; Table 3). There was significant difference in postnatal mortality between farms (Table 3).

Number of Weaned Piglets. A high degree of NEST (Table 3; Fig. 8a), COM (Table 3; Fig. 8b), and CARE (Table 3; Fig. 8c) was associated with more piglets weaned. There was no significant effect of parity on the number of weaned piglets (Table 3). More piglets were weaned in litters with many piglets born (Table 3; Fig. 9). The number of weaned piglets was not significantly affected by MD, BCS, and SL (Table 3). There was a significant difference between farms in the number of weaned piglets (Table 3).

Predictive Accuracy of Behavioral Scores for Production Parameters. Out of the 7 models (all combinations of defined scores), we found that model 6, which included COM and CARE, had the best predictive accuracy (lowest AIC values and highest AIC weights) for piglet mortality/weaned piglets (Table 4).

DISCUSSION

In accordance with a recent experimental study that documented a clear relationship between maternal behavioral scores and piglet survival (Ocepek and Andersen, 2017), we succeeded in finding similar results on 45 commercial farms with 895 LY sows. Although an increased NEST score resulted in an increased number of weaned piglets, COM and CARE had the strongest effects on both mortality and the number of weaned piglets in loose-housed sows. In fact, the maternal behavioral scores had a stronger impact on piglet survival per se than physical traits such as MD, BCS, and SL. However, these physical traits, along with parity, influenced the behavioral scores, indicating that the physical condition of the sow will affect maternal skills.

It could be questioned if farmers only scored sow COM and CARE if they found crushed piglets in the farrowing pen, which could potentially lead to higher dependence between sow care behaviors and piglet mortality. However, because it is common for the farmers to collect dead piglets in the morning, just before feeding, it is not likely that the score made by the farmer after feeding could be affected by the number of dead piglets.

Our results showed that farmers understood the qualitative scoring system after being given only verbal advice (without on-site pretraining) and that the scoring system was as simple as possible to score for farmers and, therefore, was feasible to use to score maternal care traits under commercial condition. Moreover, maternal care traits were important predictors for piglet survival. Using model selection, our results showed that a combination of COM and CARE had the best predictive accuracy for determining levels of piglet mortality/weaned piglets. Therefore, these maternal care behaviors (COM and CARE) could be implemented in the breeding goal as a novel approach to improve piglet survival and thus ensure future sustainable pig breeding.

Sows that communicated to a great extent with their piglets and were careful with their own movements when piglets were in close proximity (i.e., high scores for COM and CARE) had substantially lower postnatal mortality and weaned more piglets. In

Table 3. Influence of fixed effects on piglet mortality and survival trait

Fixed effects[1]	Mortality, %		Weaned piglets, no.	
	$F_{(n)}$	*P*-value	$F_{(n)}$	*P*-value
NEST	$2.8_{(1, 799)}$	ns[2]	$6.8_{(1, 799)}$	0.009
COM	$13.7_{(1, 799)}$	<0.001	$14.0_{(1, 799)}$	<0.001
CARE	$6.2_{(1, 799)}$	0.013	$6.8_{(1, 799)}$	0.009
Parity	$3.1_{(1, 799)}$	ns	$3.3_{(1, 799)}$	ns
Litter size	$695.1_{(1, 799)}$	<0.001	$42.1_{(1, 799)}$	<0.001
MD	$0.1_{(1, 799)}$	ns	$0.1_{(1, 799)}$	ns
BCS	$2.5_{(2, 799)}$	ns	$0.7_{(2, 799)}$	ns
SL	$0.5_{(1, 799)}$	ns	$0.5_{(1, 799)}$	ns
Farm	$2.9_{(43, 799)}$	<0.001	$2.7_{(43, 799)}$	<0.001

[1]NEST = nest building activities; COM = sow communication; CARE = sow carefulness; MD = movement disorder; SL = shoulder lesions.

[2]ns = not significant.

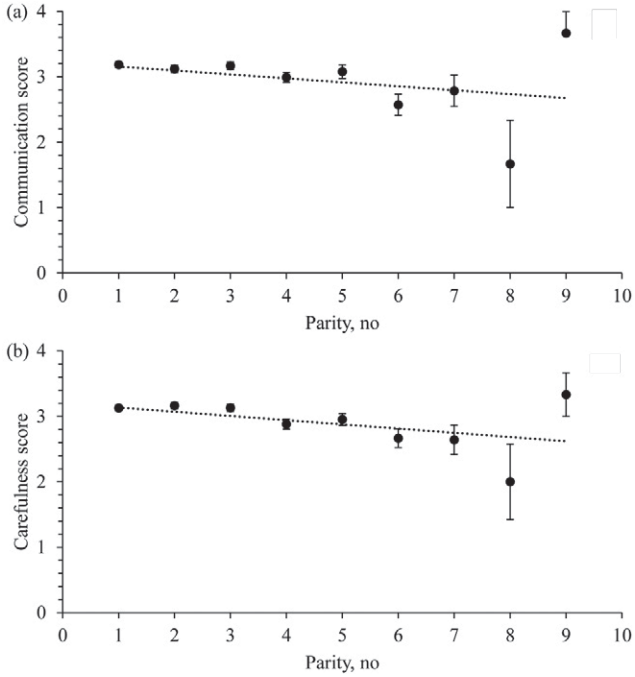


Figure 5. Relation between sow parity number and behavioral scores: (a) sow communication to piglets ($F_{1, 805}$ = 14.3, P < 0.001) and (b) sow carefulness toward piglets ($F_{1, 805}$ = 15.7, P < 0.001).

Ocepek and Andersen (2017), sows with higher COM and CARE were capable of weaning more piglets, mainly due to fewer deaths from maternal crushing. Additionally, higher COM was associated with a lower proportion of starved piglets. Starvation and crushing constitutes more than 60% of all piglet deaths in loose-housed sows (Andersen et al., 2006; Vasdal et al., 2011; Ocepek et al., 2016b). Our study suggests that there could be great potential in directly selecting for maternal care. Sows with COM score 4 (highest) as opposed to 1 (lowest) had almost 37% lower mortality and 15% more piglets weaned, whereas the values for sows with CARE scores of 4 and 1 were 15 and 8%, respectively. The trend of improving survival continued between scores 4 and 2: sows with COM scores of 4 compared with sows with COM scores of 2 had 35% lower mortality and 8% more weaned piglets, whereas the values for sows with CARE scores of 4 and 2 were 41 and 12%, respectively.

Another important finding was that COM and CARE scores were highly correlated, replicating results reported by Ocepek and Andersen (2017). It appears that COM and CARE both represent good measures or indicators of maternal care behavior during the first few days after parturition, when piglet losses are most likely to occur. As sows establish contact with their piglets, through olfactory (sniffing), auditory (grunting), and tactile (nudging) communicative cues, they can locate the piglets' position. From an evolutionary point of view, this mechanism aids sows in keeping the piglets in close proximity and protecting them from danger. Awareness of the piglets' presence helps the sow to become careful, attentive, and protective around the piglets (without trampling on them or lying on them). Therefore, stimulating sow motivation to care for her young is crucial for ensuring the future welfare and sustainability of pig production. This can be brought about through selecting for these particular maternal traits and by stimulating the sow to become more attentive through environmental factors (i.e., nest building material, good handling to prevent fear, etc.). The simple scoring, the large individual variation, and the stability of the traits irrespective of litter size and breed (e.g., 3 different breeds show similar results; Ocepek and Andersen, 2017) make them particularly suited for selection.

Although COM and CARE are similar measures of maternal care traits (i.e., highly correlated), meaning that one could replace the other, we showed that a combination of both scores had the best predictive accuracy for determining levels of piglet survival. Therefore, both scores should be further tested in nucleus herds. Calculation of heritability, genetic variation, and correlation will be estimated to determine the relationship between these scores and other registered traits included in the breeding goal. Thereafter, it can be decided if the maternal care index should be developed out of both maternal care scores or if the scores should be merged into one refined score of COM with some description of CARE added before implementing it into a breeding goal.

Maternal care scores (COM and CARE) also decreased with parity. Therefore, sows in earlier reproductive life appear to show better maternal care behavior. This is not surprising, because breeding goals have emphasized greater maternal investment earlier in life (Canario et al., 2009; Ocepek et al., 2016a). A high maternal investment early in life has a substantial future

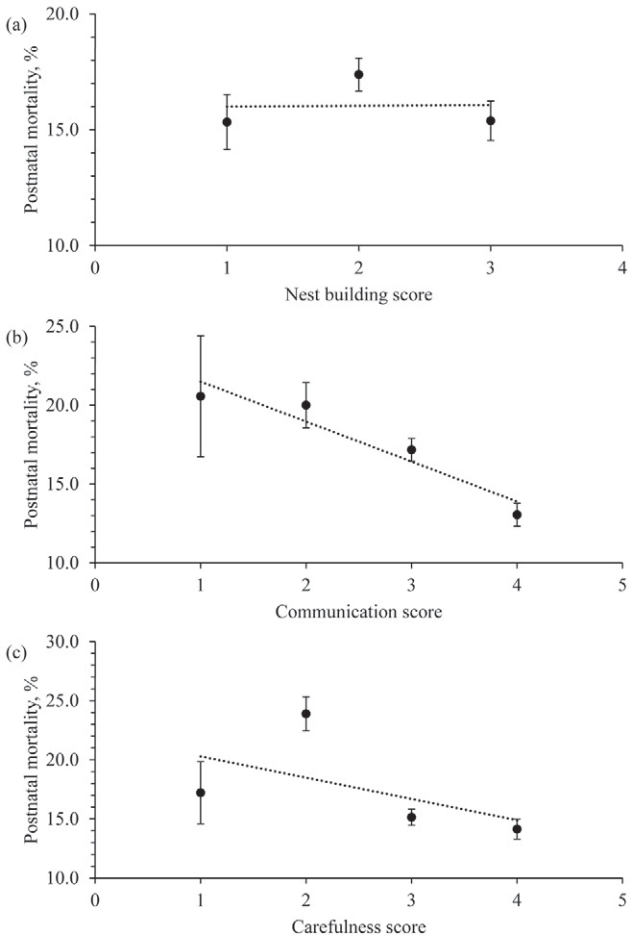


Figure 6. Relation between postnatal mortality and behavioral scores: (a) nest building ($F_{1, 799} = 2.8$, $P = 0.188$), (b) sow communication to piglets ($F_{1, 799} = 13.7$, $P < 0.001$), and (c) sow carefulness toward piglets ($F_{1, 799} = 6.2$, $P = 0.013$).

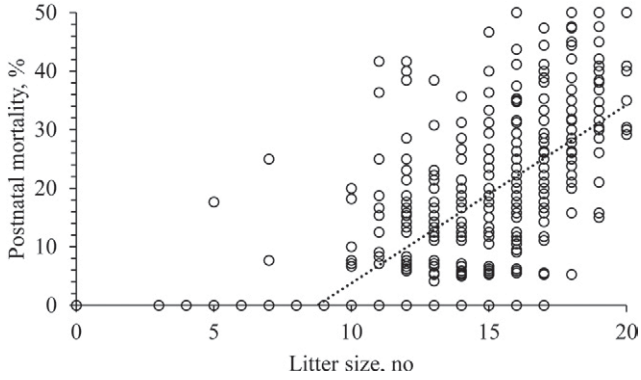


Figure 7. Relation between litter size and postnatal mortality ($F_{1, 799} = 695.1$, $P < 0.001$).

cost in that it reduces the residual reproductive value of the sow, compromising longevity. We would like to pinpoint the importance of selection during the sows' reproductive life, rather than focus on the first 2 litters.

Furthermore, sows at farrowing might respond to suboptimal physical conditions of the sow by reducing maternal care. Here, we showed that if sows had problems with moving, they had lower scores for maternal care (i.e., COM and CARE) than sows without movement problems. It is therefore crucial to have healthy sows while promoting maternal care behaviors.

For farmers, it is easier to record maternal care behaviors (COM and CARE) when the scores are simply from 1 to 4. Such scoring is also easy to implement in a breeding program. The alternative and more correct way is by using continues measures of those behaviors, because they would show exact variation in this maternal care behaviors. The weakness is that maternal care (COM and CARE) is scored on one occasion, and we do not know if the farmers get the same results by scoring several times. However, a moderate positive correlation between maternal care behaviors continuously measured and qualitative behavioral score was documented in Ocepek and Andersen (2017).

Even though sows have the internal motivation to prepare a proper nest for newborn piglets, this is mediated by their physical condition. We found that MD and BCS, 2 physical conditions, influenced NEST. Sows with MD or sows that are classified as thin or fat invest less time in NEST. Suboptimal MD or BCS makes it difficult for sows to lie down and stand up as well as to move around (Bonde et al., 2004). This result highlights the necessity of making sure that the sow is healthy and in good physical condition before farrowing to ensure that maternal behavior can proceed as optimally as possible.

Piglet survival was partly affected by NEST. Higher NEST was associated with more piglets weaned, although this higher NEST was not clearly related to lower mortality. In Ocepek and Andersen (2017), sows that engaged in more NEST also weaned more piglets, as fewer piglets died from maternal crushing. However, in their study, sows had ad libitum access to nest building material prior to parturition, whereas in our study, access varied from 0.1 to 10.0 kg. The performance of NEST is strongly affected by environmental factors (i.e., provision of nest building material; Wischner et al., 2009; Andersen et al., 2014). If amount of relevant external stimuli is insufficient or the timing before farrowing is wrong, NEST may fail to make the sow relaxed and become attentive toward her young (e.g., Wischner et al., 2009). Although there was between-sow variation in NEST scores and NEST was positively correlated with the other 2 behavioral scores as well as unaffected by parity and litter size, NEST had a minor effect on piglet survival under commercial conditions. We cannot be sure that a sufficient amount of nest building material is provided at the right time on the farms, and therefore, we cannot recommend NEST for further testing in nucleus herds.

Finally, we identified the impact of maternal care behaviors on productivity compared with physical conditions of the sows. Our results showed that maternal care behaviors are more direct predictors of

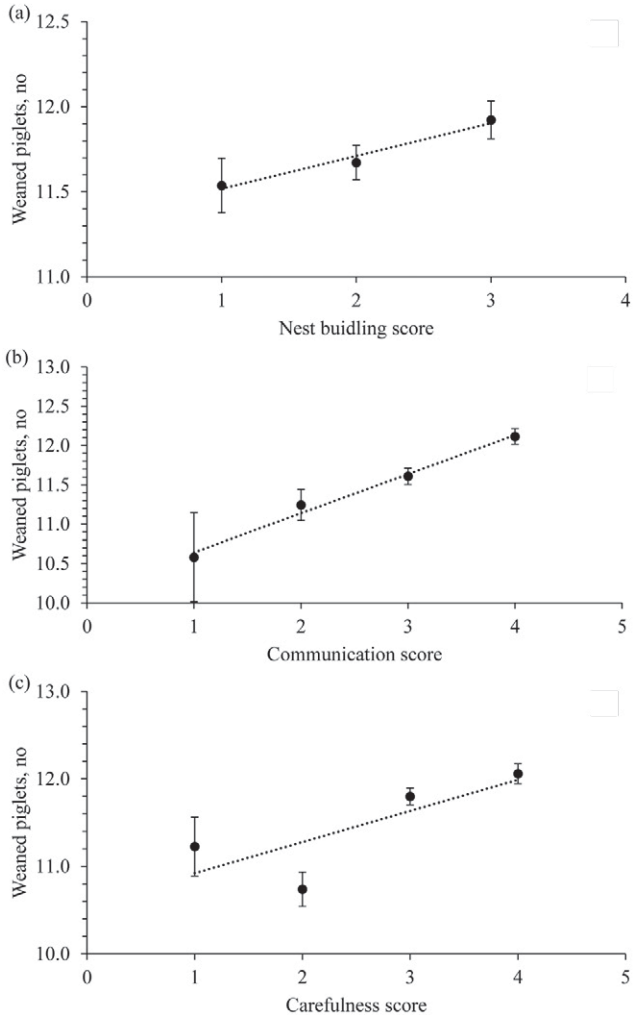


Figure 8. Relation between number of weaned piglets and behavioral scores: (a) nest building ($F_{1, 799} = 6.8$, $P = 0.009$), (b) sow communication to piglets ($F_{1, 799} = 14.0$, $P < 0.001$), and (c) sow carefulness toward piglets ($F_{1, 799} = 6.8$, $P = 0.009$).

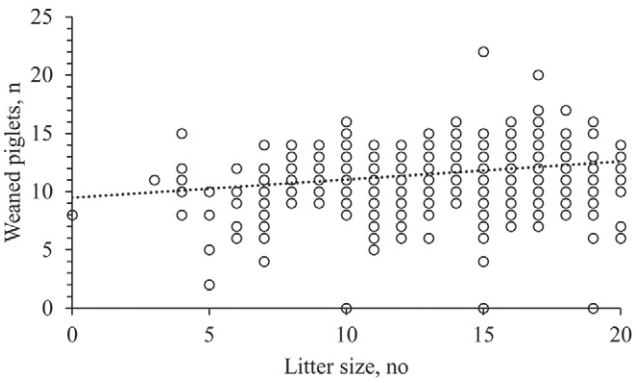


Figure 9. Relation between number of weaned piglets and litter size at birth ($F_{1, 799} = 42.1$, $P < 0.001$).

piglet survival than the physical condition of the sow. However, suboptimal physical conditions at farrowing can reduce maternal care, indicating that physical condition is likely related to productivity through its effect of the expression of maternal care. Therefore, improving sows' physical condition at farrowing promotes maternal care behaviors important for determining piglet survival.

Table 4. Predictive accuracy differences between different combination of behavioral scores for piglet mortality and survival traits

Model	Postnatal mortality,[1] %	AIC[2]	AIC weights,[3] %
1	NEST	3,787.3	0.0
2	COM	3,735.5	0.0
3	CARE	3,738.5	0.0
4	NEST and COM	3,735.9	0.0
5	NEST and CARE	3,738.2	0.0
6	COM and CARE	3,714.5	58.7
7	NEST, COM, and CARE	3,715.2	41.3
Model	Weaned piglets, no.	AIC	AIC weights, %
1	NEST	3,896.4	0.3
2	COM	3,889.0	10.8
3	CARE	3,887.8	19.8
4	NEST and COM	3,890.2	6.0
5	NEST and CARE	3,889.0	10.9
6	COM and CARE	3,886.7	34.3
7	NEST, COM, and CARE	3,888.0	17.9

[1]NEST = nest building activities; COM = sow communication; CARE = sow carefulness.

[2]AIC = Akaike information criterion (smaller value = better predictive accuracy).

[3]AIC weights = Akaike weights (higher percentage = higher predictive accuracy).

Conclusion

This study investigated the relationships between qualitative scores of maternal care behaviors (NEST, COM, and CARE), sow physical condition variables (MD, BCS, and SL), and piglet survival under commercial conditions. We found that farmers were able to implement the qualitative scoring system and that maternal care behaviors were more predictive of piglet survival (low piglet morality and more weaned piglets) than the physical condition of the sow. In particular, our results showed that a combination of COM and CARE had the best predictive accuracy for piglet mortality/weaned piglets. The large individual variation in COM and CARE and the fact that they were not affected by litter size and were easy for the farmer to record indicates that they are suitable behavioral parameters for testing in nucleus herds to be implemented in the future breeding program.

LITERATURE CITED

Animalia. 2014. The shoulder lesions report from the pig health services at Animalia 2014. Animalia, Oslo, Norway. https://www.animalia.no/contentassets/cb3db6379cef4c2f82832d17ea645cb8/bogsarrapport.pdf Accessed December 13, 2015.

Andersen, I. L., S. Berg, and K. E. Bøe. 2005. Crushing of piglets by the mother sow (*Sus scrofa*) – Purely accidental or a poor mother? Appl. Anim. Behav. Sci. 93:229–243. doi:10.1016/j.applanim.2004.11.015

Andersen, I. L., S. Berg, K. E. Bøe, and S. Edwards. 2006. Positive handling in late pregnancy and the consequences for maternal behaviour and production in sows. Appl. Anim. Behav. Sci. 99:64–76. doi:10.1016/j.applanim.2005.09.007

Andersen, I. L., G. M. Tajet, I. A. Haukvik, S. Kongsrud, and K. E. Bøe. 2007. Relationship between postnatal piglet mortality, environmental factors and management around farrowing in herds with loose-housed, lactating sows. Acta Agric. Scand., Sect. A 57:38–45. doi:10.1080/09064700601159626

Andersen, I. L., G. Vasdal, and L. J. Pedersen. 2014. Nest building and posture changes and activity budget of gilts housed in pens and crates. Appl. Anim. Behav. Sci. 159:29–33. doi:10.1016/j.applanim.2014.07.002

Bonde, M., T. Rousing, J. H. Badsberg, and J. T. Sørensen. 2004. Associations between lying-down behaviour problems and body condition, limb disorders and skin lesions of lactating sows housed in farrowing crates in commercial sow herds. Livest. Prod. Sci. 87:179–187. doi:10.1016/j.livprodsci.2003.08.005

Canario, L., Y. Billon, P. Mormède, D. Poirel, and C. Moigneau. 2009. Temperament, adaptation and maternal abilities of Meishan and Large White sows kept in a loose-housing system during lactation. In: Book of Abstracts of the 60th Annual Meeting of the European Association for Animal Production, Barcelona, Spain. p. 282.

Grandinson, K., L. Rydhmer, E. Strandberg, and K. Thodberg. 2003. Genetic analysis of on-farm tests of maternal behaviour in sows. Livest. Prod. Sci. 83:141–151. doi:10.1016/S0301-6226(03)00095-2

Ingris, 2017; https://ingris.animalia.no/IngrisWeb/login.action Accessed 15 January 2017

Lovdata, 2017. https://lovdata.no/dokument/SF/forskrift/2003-02-18-175 Accessed January 5, 2017.

Løvendahl, P., L. H. Damgard, B. L. Nielsen, K. Thodberg, G. Su, and L. Rydhmer. 2005. Aggressive behaviour of sows at mixing and maternal behaviour are heritable and genetically correlated traits. Livest. Prod. Sci. 93:73–85. doi:10.1016/j.livprodsci.2004.11.008

Nara, 2017; http://norecopa.no/files/statute.html Accessed June 01, 2017

Ocepek, M., and I. L. Andersen. 2017. What makes a good mother? Maternal behavioural traits important for piglet survival. Appl. Anim. Behav. Sci. 193:29–36. doi:10.1016/j.applanim.2017.03.010

Ocepek, M., I. Andersen-Ranberg, S. A. Edwards, and I. L. Andersen. 2016b. Udder characteristics of importance for teat use in purebred and crossbred pigs. J. Anim. Sci. 94:780–788. doi:10.2527/jas.2015-9420

Ocepek, M., I. Andersen-Ranberg, S. A. Edwards, B. Fredriksen, T. Framstad, and I. L. Andersen. 2016a. Can a super sow be a robust sow? Consequences of litter investment in purebred and crossbred sows of different parities. J. Anim. Sci. 94:3550–3560. doi:10.2527/jas.2016-0386

Ocepek, M., R. C. Newberry, and I. L. Andersen. 2017. Trade-offs between litter size and offspring fitness in domestic pigs subjected to different genetic selection pressures. Appl. Anim. Behav. Sci. 193:7–14. doi:10.1016/j.applanim.2017.03.008

Pedersen, L. J., P. Berg, G. Jørgensen, and I. L. Andersen. 2011. Neonatal piglets trait of importance for survival in crates and indoor. J. Anim. Sci. 89:1207–1218. doi:10.2527/jas.2010-3248

Rosvold, E. M., C. Kielland, M. Ocepek, T. Framstad, B. Fredriksen, I. Andersen-Ranberg, G. Næss, and I. L. Andersen. 2017. Management routines influencing piglet survival in loose-housed sow herds. Livest. Prod. Sci. 196:1–6. doi:10.1016/j.livsci.2016.12.001

Vangen, O., B. Holm, A. Valros, M. S. Lund, and L. Rydhmer. 2005. Genetic variation in sows' maternal behaviour, recorded under field conditions. Livest. Prod. Sci. 93:63–71. doi:10.1016/j.livprodsci.2004.11.007

Vasdal, G., I. Østensen, M. Melišová, B. Bozděchová, G. Illmann, and I. L. Andersen. 2011. Management routines at the time of farrowing – Effects on teat success and postnatal piglet mortality from loose housed sows. Livest. Sci. 136:225–231. doi:10.1016/j.livsci.2010.09.012

Wischner, D., N. Kemper, and J. Krieter. 2009. Nest-building behaviour in sows and consequences for pig husbandry. Livest. Prod. Sci. 124:1–8. doi:10.1016/j.livsci.2009.01.015