Individual differences in the behaviour of sows at the nest-site and the crushing of piglets

Beat Wechsler [a,*], Daniel Hegglin [b]

[a] *Abteilung Sozial- und Nutztierethologie, Zoologisches Institut, Universität Bern, Ethologische Station Hasli, Wohlenstrasse 50a, 3032 Hinterkappelen, Switzerland*
[b] *Ethologie und Wildforschung, Zoologisches Institut, Universität Zürich, Winterthurerstrasse 190, 8057 Zürich, Switzerland*

Abstract

This study examines the relationship between individual differences in the behaviour of sows, *Sus scrofa*, and piglet mortality caused by crushing. Continuous 24-h video recordings were made of 11 loose-housed sows and their litters during parturition, and during the following 10 days. Each sow and litter were kept in a pen with a straw-bedded nest-site. Piglets were defined as in danger of being crushed if they were trapped by the sow's body or if they jumped aside in response to the lying down or rolling behaviour of the sow at the nest-site. An overall score (derived from five behavioural measures) of the quality of sow behaviour in relation to crushing was computed for each sow. This score was significantly correlated with the number of piglets in danger in each litter during the first 10 days after farrowing. The 11 sows were also scored with respect to their responsiveness to playbacks of piglet distress calls. Sows with a high responsiveness had fewer of their trapped piglets crushed. Both the score of the quality of sow behaviour and the score of the sows' responsiveness to piglet distress calls were significantly negatively correlated with the percentage of liveborn piglets (born several months before or after the present study) in which crushing was the primary cause of death. In conclusion, our results provide evidence that the occurrence of crushing is significantly related to individual differences in sow behaviour.

Keywords: Pig—parental behaviour; Maternal behaviour; Crushing

* Corresponding author. Tel.: 031/631 91 54; fax: 031/631 91 41; e-mail: bwechsler@esh.unibe.ch.

1. Introduction

Pre-weaning losses of live births are a major problem in modern pig production (English and Morrison, 1984). Bøe (1994) reported that the national average in piglet mortality over the first 3 weeks of life is 14.4% in Norwegian herds. Most of the losses occur during the first week of life, and crushing of piglets by the sow accounts for a significant portion of piglet mortality (Svendsen et al., 1986; Dyck and Swierstra, 1987). In a survey of 7866 litters, Kunz and Ernst (1987) found that crushing was the cause of death in 47.4% of all losses of liveborn piglets.

To reduce piglet mortality, and in particular losses due to crushing, farrowing crates have been introduced to intensive pig production. They are designed to restrict gross body movements of the sow and to make the floor area outside the crate safe for the piglets. Owing to the extreme confinement in the crates, however, the sows are also much restricted in their pre-parturient behaviour. They are prevented from choosing a nest-site and cannot perform nest-building behaviour that is typical of domestic pigs (Stolba and Wood-Gush, 1984; Jensen, 1986, 1989). Farrowing crates are therefore judged to be far from ideal for the sow with respect to animal welfare (Fraser and Broom, 1990), and research on alternative farrowing systems has intensified in the last years (Baxter, 1991; Schmid, 1993; Phillips and Fraser, 1993).

Crushing of piglets can be an important disadvantage of alternative farrowing systems with loose-housed sows. For example, in the Family Pen System developed by Stolba (1981), 10.0% of the piglets born alive over a period of 3 years ($N = 72$ litters) were crushed by the sow (Wechsler et al., 1991). However, the effectiveness of farrowing crates in reducing piglet mortality caused by crushing is also controversial. Blackshaw et al. (1994), for example, reported that in a piggery with farrowing crates, 9.2% of all liveborn piglets were crushed by the sows over a period of 12 months ($N = 170$ litters), and Fraser (1990) concluded that crushing probably remains the major cause of death when farrowing crates are used.

There are indications that the occurrence of piglet losses due to crushing may be influenced by individual differences in sow behaviour. Signoret et al. (1975) reported that some sows are very responsive to squeals of their young and will rise in response to the vocalisations of a trapped piglet, whereas other sows do not react at all. Similarly, Hutson et al. (1991, 1993) found large individual differences in the responsiveness of sows to piglet distress calls that were played back when the sow was lying down. These studies did not, however, provide evidence that individual differences in sow behaviour are related to the percentage of piglets crushed by a given sow.

The aim of the present study was to identify characteristics of sow behaviour that are associated with an increased risk of crushing of piglets, and to examine the relationships between individual differences in the behaviour of sows at the nest-site, the responsiveness to piglet distress calls and the percentage of piglets crushed. It was hypothesised that sows which rarely perform behaviour that is risky for the piglets or regularly respond to piglet distress calls are less likely to have piglets in danger of being crushed and to actually crush piglets.

2. Methods

2.1. Housing

The study was done in a technologically improved version of the Family Pen System (Wechsler, 1996). Three units of this housing system were built side by side in an open-fronted building on a commercial farm. During pregnancy the sows were kept in groups of four to five sows. A few days before farrowing, they were separated in individual pens (Fig. 1). The walls of these farrowing pens were opaque and 1.1 m high. Each pen had a floor area of 3 m × 2.5 m and was divided by a wooden barrier (20 cm high) into a straw-bedded nest-site (3 m × 1.3 m) and an area with a concrete floor (3 m × 1.2 m). All sows farrowed in the straw-bedded part of the pen. In the centre of the pen and next to the nest-site there was a piglet nest (0.8 m × 0.6 m) with a heating lamp and a heating plate on the floor. No guard rails were used around the perimeter of the pen. The activity area was connected to a corridor that led to other parts of the Family Pen System. However, during the first 2 weeks after farrowing the gate at the end of this corridor was closed. The drinkers for the sows and the piglets were placed at the end of this corridor to keep humidity away from the nest-site. The sows were fed twice a day with liquid food in individual feeding stalls outside the farrowing pens.

Data collection included (a) video observations of the behaviour of the sows and their piglets at the nest-site, (b) experiments on the sows' responsiveness to playbacks of
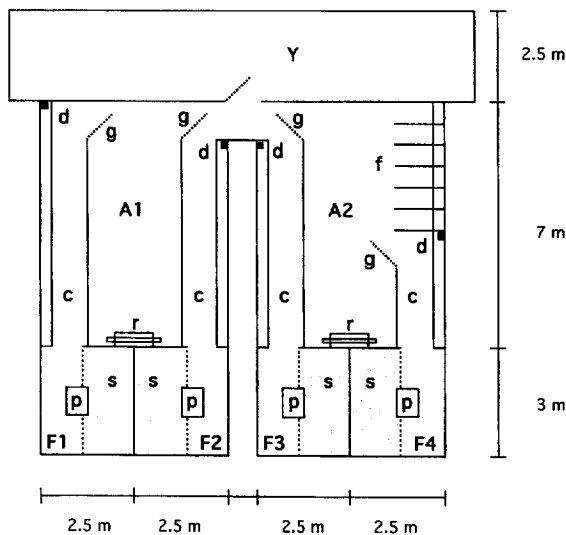

Fig. 1. Ground plan of one unit of the Family Pen System with four farrowing pens (F1–F4), two activity areas (A1, A2) and an unsheltered outside yard (Y). The pen includes individual feeding stalls (f), four sites with drinkers (d), four piglet nests (p) and two straw racks (r). The sows were separated in the farrowing pens by closing the gates (g) at the end of the corridors (c). Half of the floor of the farrowing pens was covered with straw (s).

piglet distress calls and (c) pathological examinations of dead piglets to quantify the proportion of piglet losses caused by crushing.

2.2. Animals and behavioural observations

The behaviour of two primiparous and nine multiparous (parity two to six) sows was continuously recorded with a time-lapse recorder (Panasonic NV-8050) during parturition, and during the following 10 days. The sows were Large White ($N = 5$), Swiss Landrace ($N = 5$) or Large White × Swiss Landrace crossbred ($N = 1$). An inspection of the data revealed no significant strain differences in sow behaviour and piglet losses due to crushing. The parturition dates were between July and October 1992, and each sow was observed with only one litter. The mean ($\pm$ SD) number of piglets born alive in the 11 litters was 10.8 ± 2.7. The video camera had a wide-angle lens and was fixed 3 m above the nest-site. The speed of the video tape was 16 times slower than normal, with an interval of 0.32 s between frames. Night-time video-recording was assisted by illumination from a 40 W light.

The protocols focused on the behaviour of sows and piglets. The following behaviour patterns, expected to be related to the risk of crushing, were recorded:
1. Lying down vertically: after 'kneeling' (the animal stands on the carpals of one or both forelegs and the hind quarters are still in the standing position) a sow lowers her hind quarters vertically or slightly inclined.
2. Flopping straight down: after 'kneeling' a sow lets her hind quarters fall to one side.
3. Rolling: a lying sow rolls her body longitudinally from a vertical to a lateral position.
4. Piglet present: a piglet is within a distance of 50 cm of a 'kneeling' sow.
5. Jumping aside: a piglet reacts by a reflex-like side jump when a sow is 'lying down vertically', 'flopping straight down' or 'rolling'.
6. Piglet trapped: a piglet is covered partly or completely by the body of a sow.

An overall score of the quality of sow behaviour in relation to crushing was computed for each sow. This score included the following five measures:
1. the average frequency of lying down of the sow in the nest per day;
2. the average frequency of 'rolling' events of the sow in the nest per day;
3. the percentage of all lying down events in which the sow 'flopped straight down';
4. the percentage of all lying down events in which the sow lay down to the side with more 'piglets present' than on the opposite side;
5. the average percentage of all piglets of a litter that were 'present' when the sow was lying down.

The 11 sows were ranked for these five measures with the higher values of the behaviour receiving lower ranks (because high values of behaviour are more likely to result in crushing). An average rank was computed for each sow as a score of the quality of sow behaviour (see Table 1).

2.3. Responsiveness to piglet distress calls

Distress calls of one piglet of each litter were tape recorded (UHER Report 4000 IC Recorder) by seizing the piglet around its chest and raising it in the air with its head

Table 1
Five measures of sow behaviour and overall score of the quality of sow behaviour in relation to crushing

Sow	Rate of lying down [a]	Rate of rolling [b]	Flopping straight down [c]	Lie on piglets' side [d]	Piglets present [e]	Quality of sow behaviour [f]
1F	8.1	3.9	2.4	31.8	21.3	6.6
1H	10.2	1.4	12.6	3.8	32.4	6.2
2A	8.6	8.5	1.2	25.6	20.7	6.4
2C	13.2	7.4	8.9	25.9	29.8	3.3
2D	13.9	11.2	12.3	14.3	23.9	3.8
2E	12.1	9.6	2.3	9.4	28.0	5.4
3E	8.5	4.3	0.0	3.7	8.0	9.5
3F	11.1	1.8	0.0	13.3	8.6	8.4
3G	11.1	3.0	8.9	21.4	26.8	5.5
3H	6.9	1.3	2.9	21.4	39.2	6.9
3I	9.9	5.1	15.5	21.3	39.3	4.0

[a] Average frequency of lying down of the sow in the nest per day.

[b] Average frequency of 'rolling' events of the sow in the nest per day.

[c] Percentage of all lying down events in which the sow 'flopped straight down'.

[d] Percentage of all lying down events in which the sow lay down to the side with more 'piglets present' than on the opposite side.

[e] Average percentage of all piglets of a litter that were 'present' when the sow was lying down.

[f] Average rank over the five measures (see Section 2).

downwards. These recordings were played back to the mother of the piglet on three occasions when she had just finished the first lying down behaviour at the nest-site after feeding time. The loud-speaker was placed in the piglet nest. Each playback was played at natural loudness and lasted for 1 min. The experiment was not carried out until the piglets were at least 3 days old in order to avoid any extra excitement of the sows in the first few days after farrowing. The responsiveness to piglet distress calls was scored by the number of replicates in which a given sow changed from the lying to a sitting or standing position during the playback. In order to avoid a sow still being confronted with piglet distress calls once she had shown a maximal response, the playback was immediately stopped as soon as she stood on four legs. As a control, each sow was also played a recording of a calling bird on three occasions when she had just lain down at the nest-site after feeding time. These playbacks were of the same duration and loudness as the playbacks of piglet distress calls.

2.4. Trapping and crushing of piglets

Whenever a sow was lying down ($N = 983$ events) or 'rolling' ($N = 509$ events) at the nest site it was judged whether there were any piglets 'in danger' or not. Piglets were defined as 'in danger', if they either 'jumped aside' in response to the sow's behaviour or if they were 'trapped'. If either the farmer or an observer was present when a piglet was 'trapped', and if the sow did not react at all for 1 min, the piglet was saved by forcing the sow to stand up.

The present study was part of a long-term study of the technologically improved version of the Family Pen System (Wechsler, 1996). From June 1991 to July 1993

piglets that died in the Family Pen System were brought to the Department of Veterinary Pathology at the University of Zürich to determine whether they had been crushed by the sow. Based on the pathologists' reports, crushed piglets were assigned to two groups in which crushing was either the primary or secondary cause of death. Crushing was judged to be only the secondary cause of death if there were signs of a reduced viability of the piglet (birth weight 800 g or less, malformations, insufficient milk intake, diseases). For all 11 sows the percentages of piglets crushed were computed separately (a) for the litters that were observed in the present study (July–October 1992) and (b) for 25 litters that were raised before or afterwards (June 1991–July 1993). Because some piglets of the former litters were saved by an observer from being crushed only percentages of the latter litters were included in the analysis.

2.5. Statistical analysis

The following non-parametric statistics were used: Wilcoxon matched-pairs signed-ranks test (Siegel and Castellan, 1988), Spearman rank correlation coefficient (Siegel and Castellan, 1988), Trend-test by Jonckheere (Bortz et al., 1990). The sample size was $N = 11$ sows, unless one or more sows did not show the behaviour under analysis. All analyses were performed using Systat (Wilkinson, 1992).

3. Results

3.1. Sow behaviour and piglets in danger

Both lying down and 'rolling' of the sows at the nest-site led to situations in which piglets were judged to be 'in danger'. In 144 (14.6%) out of 983 lying down events and 125 (24.6%) out of 509 'rolling' events there was at least one of the piglets of the litter 'in danger'. When a sow was lying down it was differentiated whether she was 'lying down vertically' ($N = 915$ events) or 'flopping straight down' ($N = 68$ events). With two of the 11 sows 'flopping straight down' was never observed. In the other sows the percentage of lying down events in which there was at least one piglet 'in danger' was significantly increased when the sow was 'flopping straight down' compared with when she was 'lying down vertically' (average 48.6% vs. 13.4%; Wilcoxon matched-pairs signed-ranks test: $z = 2.192$, $N = 9$, $P < 0.03$, two-tailed).

The percentage of lying down events in which there was at least one piglet 'in danger' was significantly increased if the sow lay down to the side with more 'piglets present' than to the side with fewer 'piglets present' (average 58.8% vs. 9.4%; Wilcoxon matched-pairs signed-ranks test: $z = -2.845$, $N = 11$, $P < 0.005$, two-tailed). It was also found that the average number of 'piglets present' was significantly higher in lying down events in which there was at least one piglet 'in danger' compared with lying down events in which no piglet was judged to be 'in danger' (average 4.3 vs. 1.9 piglets; Wilcoxon matched-pairs signed-ranks test: $z = 2.934$, $N = 11$, $P < 0.005$, two-tailed).

Based on the results presented above five behavioural measures were included in an overall score of the quality of sow behaviour in relation to crushing (Table 1). The sow

Table 2
Responsiveness of individual sows to three playbacks of piglet distress calls, number of piglets 'trapped' during the first 10 days after farrowing and number of 'trapped' piglets (with percentages in parentheses) that were either crushed by the sow or saved by an observer

Sow	No. of responses to playbacks	No. of piglets trapped	No. of piglets crushed or saved
1F	2	29	3 (10.3)
1H	3	11	0 (0.0)
2A	1	17	0 (0.0)
2C	3	16	1 (6.3)
2D	0	37	9 (24.3)
2E	0	16	2 (12.5)
3E	3	0	0
3F	3	2	0 (0.0)
3G	0	9	3 (33.3)
3H	2	13	7 (53.8)
3I	2	49	5 (10.2)

with the lowest overall score was expected to be the one with the highest frequency of situations with a risk of crushing one of her piglets. As expected with such a post hoc scoring method, there was a strong negative correlation between the overall score of the quality of sow behaviour and the number of piglets 'in danger' in each litter (standardised for the actual litter size on each day) during the first 10 days after farrowing ($r_s = -0.855$, $N = 11$, $P < 0.001$, one-tailed).

3.2. Sow responsiveness to piglet distress calls

As expected, the sows changed more often from a lying to a sitting or standing position in experiments with playbacks of piglet distress calls than in experiments with playbacks of a calling bird (Wilcoxon matched-pairs signed-ranks test: $z = -2.232$, $N = 11$, $P < 0.02$, one-tailed). The 11 sows reacted in 19 (57.6%) out of 33 experiments with a playback of piglet distress calls but in only five (15.2%) out of 33 experiments with a control playback. The sows differed in the number of experiments in which they reacted to the playback of piglet distress calls (Table 2). Sows with a high responsiveness to piglet distress calls had significantly fewer of their 'trapped' piglets crushed or saved by an observer from being crushed than sows with a low responsiveness (Trend-test by Jonckheere: $N = 10$, $P < 0.05$, data of sows with one or two responses to playbacks were pooled into one category). Sows that never reacted to a playback of piglet distress calls had 14 (22.6%) out of 62 'trapped' piglets crushed or saved whereas sows that reacted in all three experiments had only one (3.4%) out of 29 'trapped' piglets crushed.

3.3. Sow behaviour and piglet losses caused by crushing

For each sow, the percentage of piglets born alive that were crushed in her litters born between June 1991 and July 1993 was calculated separately for piglets in which

crushing was judged to be the primary or secondary cause of death. An average of 2.3 ± 1.2 litters per sow was used for this calculation, and the 11 litters observed in this study were excluded from the analysis. The percentage of piglets in which crushing was judged to be the primary cause of death was significantly correlated with the overall score of the quality of sow behaviour ($r_s = -0.616$, $N = 11$, $P < 0.05$, one-tailed) and with the sows' responsiveness to piglet distress calls ($r_s = -0.617$, $N = 11$, $P < 0.05$, one-tailed). On the other hand, there were no significant correlations between the percentage of piglets in which crushing was judged to be the secondary cause of death and these two measures (quality of sow behaviour: $r_s = 0.528$, $N = 11$, $P > 0.05$, two-tailed; responsiveness to piglet distress calls: $r_s = 0.181$, $N = 11$, $P > 0.5$, two-tailed). As there were differences in the parity of the sows, correlations between parity and the percentages of piglets in which crushing was judged the primary or secondary cause of death were calculated for all litters included in this analysis to check for possible effects of sow age on crushing. Both correlations were not significant (primary cause of death: $r_s = 0.262$, $N = 25$, $P > 0.2$, two-tailed; secondary cause of death: $r_s = -0.176$, $N = 25$, $P > 0.2$, two-tailed).

The overall score of the quality of sow behaviour was not significantly correlated with the sows' responsiveness to piglet distress calls ($r_s = 0.379$, $N = 11$, $P > 0.2$, two-tailed). There was also no significant correlation between the percentages of piglets in which crushing was judged to be the primary and secondary cause of death ($r_s = -0.132$, $N = 11$, $P > 0.5$, two-tailed).

4. Discussion

In the present study, we found that the occurrence of situations in which one or more piglets is in danger of being crushed is related to the quality of the lying down behaviour of the sow at the nest-site. The percentage of lying down events with at least one piglet in danger was much increased if the sow flopped straight down compared with when she lay down vertically. The risk of crushing also increased if the sow did not pay attention to the distribution of the piglets and lay down to the side with more piglets present. Schmid (1991) also reported that there are fewer dangerous situations for the piglets if the sow lowers her hind quarters vertically. In addition, he found that the risk of crushing is reduced if the piglets are grouped on one side of the sow before she lays down.

When a piglet is trapped by the sow's body, it can be vital for its survival that the sow changes her posture. Several studies have shown that auditory stimuli (piglet distress calls) are effective in eliciting posture changes in the sow (Cronin and Cropley, 1991; Hutson et al., 1991, 1992, 1993). The results of Hutson et al. (1992) suggested that the sows' responsiveness to piglet distress calls is innate and not influenced by previous exposure to piglet squeals or experience of maternal behaviour. Hutson et al. (1993) reported that loud playbacks of piglet distress calls are most likely to induce posture changes in the sows, and that the probability of a posture change does not increase with the duration of a playback. It is typical for playback experiments with

piglet distress calls that there is much variation in the responsiveness of the sows (Hutson et al., 1991, 1993). In a survey of several studies, Hutson et al. (1993) found that only about 60% of sows showed a posture change in response to a playback. Similarly, in the present study seven (63.6%) out of 11 sows changed their posture in at least two out of three replicates with playbacks of piglet distress calls.

It is plausible to assume that a sow with a high responsiveness to playbacks of piglet distress calls will have fewer piglets crushed. To our knowledge, however, no data have been published before to confirm this assumption. In the present study, we have shown that the percentage of trapped piglets that were crushed (or saved by an observer from being crushed) during the 10 days of video observations was related to the sows' responsiveness to playbacks of piglet distress calls. Moreover, there was a significant negative correlation between the sows' responsiveness to piglet distress calls and the percentages of liveborn piglets that were crushed in litters born several months before or after the playback experiment.

The 11 sows in this study differed in their behaviour at the nest-site. As expected, the overall score of the quality of sow behaviour was significantly correlated both with the incidence of situations in which there was a risk of crushing and with the percentage of liveborn piglets in which crushing was judged to be the primary cause of death. Given the fact that the sample size of the present study was rather small, it is impressive that there was such a clear relation between sow behaviour and piglet losses due to crushing. We therefore conclude that individual differences in sow behaviour may account for a significant share of the variation found between different studies in which crushing losses in farrowing crates and farrowing pens were compared (Fraser, 1990; Schmid, 1991).

It is not yet known whether the variation observed in the sows' behaviour at the nest-site and in their responsiveness to piglet distress calls reflects underlying genetic variation. Hutson et al. (1993) hypothesised that this may be true for the sows' responsiveness to piglet distress calls. As crushing of piglets results in fitness costs, it is reasonable to assume that there has been selection for behavioural characteristics that reduce the risk of crushing in the ancestor of our domestic pigs, the wild boar. One would therefore not expect much genetic variation in such behaviour. However, compared with the wild boar the behaviour of the domestic pig may have been altered by selection for large sows which tend to be less agile and for docile sows which may also be less responsive to piglet distress calls. Moreover, the use of farrowing crates over the last 25 years may have promoted the reproductive success of sows that would have had problems with crushing in loose housing systems.

If behavioural characteristics that are responsible for crushing were heritable, selective breeding of daughters of sows with few losses due to crushing should be successful in reducing piglet mortality within a herd. The results of the present study suggest that the risk of crushing is rather constant over time for a given sow. The quality of sow behaviour as well as the sow's responsiveness to piglet distress calls were significantly correlated with the overall percentage of piglet losses due to crushing in litters that were born several months before or after the 10 day video observations and the playback experiments. It may therefore be possible already to assess a sow's tendency to crush piglets when her first litter is born. Based on the results of our study, such an assessment

could be made by detailed observations of the sow's behaviour at the nest-site and by testing her responsiveness to piglet distress calls.

If there is genetic variation for leg-weakness this trait should, of course, also be selected against, as it may lead to changes in sow behaviour that increase the risk of crushing. Our sows were not checked for leg-weakness by an experienced veterinarian, and so we could not include this factor in the analysis of piglet losses due to crushing. However, behavioural problems due to leg-weakness would probably increase with the age of the sow, and we found no significant correlation between parity and the percentage of piglets crushed.

Malnutrition, low birth weight, malformations or diseases may result in weakened piglets that are either slow in reacting or do not react at all to the body movements of the sow. As a consequence, such piglets are more likely to be crushed than healthy piglets (Svendsen et al., 1986; Fraser, 1990). When measuring the influence of sow behaviour on piglet mortality due to crushing, it is therefore important to differentiate between piglets in which crushing is the primary or secondary cause of death. This was confirmed by the present study. The overall score of the quality of sow behaviour as well as the sows' responsiveness to piglet distress calls were only significantly corre-lated with the percentage of liveborn piglets in which crushing was judged to be the primary cause of death.

In conclusion, the results of our study show that the behaviour of the sow is correlated with the incidence of situations in which piglets are in danger of being crushed and with the percentage of piglets for which crushing is the primary cause of death. We therefore suggest that the quality of sow behaviour should be taken into account when comparisons are made between different farrowing systems (e.g. farrow-ing crates vs. farrowing pens). We also think that it would be useful to investigate the heritability of the quality of sow behaviour at the nest-site and the sows' responsiveness to piglet distress calls.

Acknowledgements

References

Baxter, M.R., 1991. The 'Freedom' farrowing system. Farm Build. Prog., 104: 9–15.
Blackshaw, J.K., Blackshaw, A.W., Thomas, F.J. and Newman, F.W., 1994. Comparison of behaviour patterns of sows and litters in a farrowing crate and a farrowing pen. Appl. Anim. Behav. Sci., 39: 281–295.
Bøe, K., 1994. Variation in maternal behaviour and production of sows in integrated loose housing systems in Norway. Appl. Anim. Behav. Sci., 41: 53–62.

Bortz, J., Lienert, G.A. and Boehnke, K., 1990. Verteilungsfreie Methoden in der Biostatistik. Springer, Berlin.

Cronin, G.M. and Cropley, J.A., 1991. The effect of piglet stimuli on the posture changing behaviour of recently farrowed sows. Appl. Anim. Behav. Sci., 30: 167–172.

Dyck, G.W. and Swierstra, E.E., 1987. Causes of piglet death from birth to weaning. Can. J. Anim. Sci., 67: 543–547.

English, P.R. and Morrison, V., 1984. Causes and prevention of piglet mortality. Pig News Inf., 5: 369–376.

Fraser, A.F. and Broom, D.M., 1990. Farm Animal Behaviour and Welfare. Ballière Tindall, London.

Fraser, D., 1990. Behavioural perspectives on piglet survival. J. Reprod. Fertil. Suppl., 40: 355–370.

Hutson, G.D., Wilkinson, J.L. and Luxford, B.G., 1991. The response of lactating sows to tactile, visual and auditory stimuli associated with a model piglet. Appl. Anim. Behav. Sci., 32: 129–137.

Hutson, G.D., Argent, M.F., Dickenson, L.G. and Luxford, B.G., 1992. Influence of parity and time since parturition on responsiveness of sows to a piglet distress call. Appl. Anim. Behav. Sci., 34: 303–313.

Hutson, G.D., Price, E.O. and Dickenson, L.G., 1993. The effect of playback volume and duration on the response of sows to piglet distress calls. Appl. Anim. Behav. Sci., 37: 31–37.

Jensen, P., 1986. Observations on the maternal behaviour of free-ranging domestic pigs. Appl. Anim. Behav. Sci., 16: 131–142.

Jensen, P., 1989. Nest site choice and nest building of free-ranging domestic pigs due to farrow. Appl. Anim. Behav. Sci., 22: 13–21.

Kunz, H.-J. and Ernst, E., 1987. Abgangsursachen bei Ferkeln. Züchtungskunde, 59: 135–145.

Phillips, P.A. and Fraser, D., 1993. Developments in farrowing housing for sows and litters. Pig News Inf., 14: 51–55.

Schmid, H., 1991. Natürliche Verhaltenssicherungen der Hausschweine (*Sus scrofa*) gegen das Erdrücken der Ferkel durch die Muttersau und die Auswirkungen haltungsbedingter Störungen. Ph.D. Thesis, University of Zürich, 90 pp.

Schmid, H., 1993. Ethological design of a practicable farrowing pen. In: M. Nichelmann, H.K. Wierenga and S. Braun (Editors), Proc. of the Int. Congress on Applied Ethology, KTBL, Darmstadt, pp. 238–242.

Siegel, S. and Castellan, N.J., 1988. Nonparametric Statistics for the Behavioral Sciences. McGraw-Hill, New York.

Signoret, J.P., Baldwin, B.A., Fraser, D. and Hafez, E.S.E., 1975. The behaviour of swine. In: E.S.E. Hafez (Editor), The Behaviour of Domestic Animals. Ballière Tindall, London, pp. 295–329.

Stolba, A., 1981. A family system in enriched pens as a novel method of pig housing. In: R. Ewbank (Editor), Alternatives to Intensive Husbandry Systems. Proc. Symp. Universities Federation for Animal Welfare, Wye, 1981, UFAW, Potters Bar, pp. 52–67.

Stolba, A. and Wood-Gush, D.G.M., 1984. The identification of behavioural key features and their incorporation into a housing design for pigs. Ann. Rech. Vét., 15: 287–298.

Svendsen, J., Bengtsson, A.Ch. and Svendsen, L.S., 1986. Occurrence and causes of traumatic injuries in neonatal pigs. Pig News Inf., 7: 159–170.

Wechsler, B., 1996. Rearing pigs in species-specific family groups. Anim. Welfare, 5: 25–35.

Wechsler, B., Schmid, H. and Moser, H., 1991. Der Stolba-Familienstall für Hausschweine: ein tiergerechtes Haltungssystem für Zucht- und Mastschweine. Birkhäuser, Basel.

Wilkinson, L., 1992. Systat: The System for Statistics. Systat, Evanston, IL.