Pressure load on specific body areas of gestating sows lying on rubber mats with different softness

A. Schubbert,* E. Hartung,† and L. Schrader*2

*Institute of Animal Welfare and Animal Husbandry, Friedrich-Loeffler-Institut, Doernberstrasse 25/27, 29223 Celle, Germany; and †Faculty of Agricultural and Nutritional Science, Institute of Agricultural Engineering, Christian-Albrechts-University Kiel, Max-Eyth-Strasse 6, 24098 Kiel, Germany

ABSTRACT: Rubber mats offer a possibility to increase lying comfort for sows with positive effects on sow lying behavior and health. However, until now, no information has been reported about the relationship between the softness of rubber mats and the pressure load on certain body areas of sows. We used a total of 68 (40 multiparous, 28 primiparous) German Landrace × German Landrace sows with a BW within the range of 90 to 330 kg (divided in 3 weight classes) to measure peak force and distribution of pressure during lying in the sternal and half recumbent position. Measures were done in an experimental pen that was equipped with a pressure sensor map system (5400 NTL; Tekscan Inc., Boston, MA). Three rubber mats differing in softness (penetration depth: hard mat, 4.0 mm [HM]; soft mat, 14.6 mm [SM]; very soft mat, 43.0 mm [VSM]) were tested and compared to concrete floor (CF) as a reference. Pressure load was analyzed in the sternal position for the sternum, belly, and ham body regions and also in the half-recumbent position for the shoulder. For each lying position we determined the body region with the highest pressure load and analyzed the peak force (PF) and the contact area (CA) using a mixed model ANOVA (MIXED procedure of SAS Enterprise, version 4.3., SAS Inst. Inc., Cary, NC) with floor type, weight class of sows, and their interaction as fixed factors. Overall, the highest values for PF in the sternal position were found on the sternum (median: 1.62 N/cm²) and in the half-recumbent position on the shoulder (median: 2.72 N/cm²). In the sternal position PF on the sternum was lower on VSM compared to CF (P = 0.001). In the half-recumbent position PF on the shoulder was lower on VSM compared to CF (P = 0.013) and compared to HM (P = 0.011). The weight of the sows affected PF on the sternum in the sternal position, with lower values in weight class 1 compared to weight class 2 (P = 0.001) and weight class 3 (P = 0.002). Contact area under the sternum was larger on SM (P = 0.016) and VSM (P = 0.008) compared to CF in the sternal position, and this was affected by weight class (P = 0.0002). In the half-recumbent position floor type did not affect CA under the shoulder, but CA was larger in weight classes 2 and 3 compared to weight class 1 (all P < 0.05). Assuming that a reduced PF in combination with pressure distributed over a larger area will increase lying comfort, hard rubber mats do not seem to offer a high lying comfort with regard to pressure load on debited body regions such as the sternum or shoulder.

Key words: lying comfort, pigs, pressure load, rubber mat

INTRODUCTION


Lying comfort is important for sow welfare because sows spend approximately 80% of their time lying (Buckner et al., 1998). Housing systems for sows usually have fully or partially slatted concrete flooring for manure removal. However, such manure systems are not compatible with bedding (Scott et al., 2006). Rubber mats have been tested as an alternative floor to improve comfort for farrowing (Gravås, 1979; Boyle et al., 2000; Farmer et al., 2006; Zurbrigg, 2006) and gestating sows (Tuyttens et al., 2008; Elmore et al., 2010). With rubber mats, sows increased lying times (Gravås,
1979; Tuyttens et al., 2008) and experienced less slipping and longer kneeling durations (Boyle et al., 2000). Lying in the half-recumbent position was observed more often on rubber mats than lying in the sternal position (Boyle et al., 2000; Elmore et al., 2010). In addition, rubber mats can also reduce shoulder lesions in sows (Zurbrigg, 2006). In all these studies only 1 type of mat was tested, and mat softness was not considered, although the mat softness may likely affect sow lying comfort. It can be assumed that with increasing softness, pressure load will be reduced by a decrease in peak force and an increase in contact area, particularly under prominent bones like the spina scapulae of the shoulder. Until now pressure loads on different body parts of sows lying in different positions and on rubber mats of different softness have been unknown. The aim of our study was to examine 1) under which sow body part pressure load would be highest and 2) which mat softness would reduce the pressure load depending on lying position and sow weight.

MATERIAL AND METHODS

Animals, Housing, and Feeding

The experiment was conducted at the research station of the Friedrich-Loeffler-Institut in Mariensee, Germany. We used a total of 68 (40 multiparous sows with 2 to 8 lactations; 28 primiparous sows) German Landrace × German Landrace sows from the sow herd of the research station. None of the sows were lactating during the experiments. At least 1 d before the experiments 4 sows were moved into an experimental room in which they were kept individually in stalls (1.6 × 0.6 m) equipped with rubber mats (0.8 × 1.5 m). All sows were offered water from nipple drinkers (Suevia Haiges GmbH, Kirchheim/Neckar, Germany) and fed once a day with a feeding ration exceeding their nutritional requirements.

Experimental Design

The main factors tested in our study were the different floors and the weight of sows. Three different rubber mats and a concrete floor were used. Rubber mats were developed by Kraiburg, Elastik GmbH ( Tritmoning, Germany), and the mats differed in softness (hard, soft, very soft) as a result of different textures of the underside of the mats. The softness of mats had been measured before the experiments with a calotte (a hemispheric metal object with a radius of 120 mm) and a penetration force of 200 kg. The very soft rubber mat (VSM) had a height of 6.0 cm and a penetration depth of 4.0 mm. All rubber mats measured 1.2 × 1.8 m. For a control we used a concrete floor (CF) covered with floor screed (MEM Schnell Estrich, Leer, Germany), resulting in a smooth surface.

The 68 sows from the pool mentioned above had BW ranging from 90 to 330 kg. The weights of the sows were immediately assessed before pressure measurement using a digital pig scale (DWI-3006I, DMS-Waagen, Heinsberg, Germany) with a resolution of ±0.1 kg. Weights were categorized in 3 classes. Weight of sows in class 1 ranged from 90 to 170 kg (135.7 ± 19.7 kg), those in class 2 ranged from 171 to 210 kg (190.0 ± 12.0 kg), and those in class 3 ranged from 211 to 325 kg (254.0 ± 31.5 kg). For all sows BCS was also measured according to a scoring scheme ranging from 1 (very thin) to 5 (very fat) as described by Charette et al. (1996). Furthermore, lameness and claw condition were assessed using the scoring system described by Bonde et al. (2004). Sows showing limb or claw lesions were not included in the experiment.

The different floors were tested in 4 successive trials starting with HM, followed by SM, CF, and VSM. Successive testing of floors was chosen to prevent deterioration by permanent retrofitting of the experimental pen (see below). We tested 28 sows in the HM trial, 29 sows in the SM trial, 33 sows in the CF trial, and 28 sows in the VSM trial. As the sows were taken from a pool of 68 sows, this implicates that in part sows were repeatedly tested on different floors. However, a sow was tested only once on a particular floor. We did not perform repeated measurements of sows on different floors because of the sows’ weight gain between measurements. The number of sows in the weight classes was equally distributed across floors, with about 8 sows in each weight class per floor type.

Pressure Measurement

Experimental Pen. Pressure measurements were conducted in an experimental pen (1.8 × 0.9 m; Fig. 1) located in the experimental room. This pen had a frame of steel bars and 2 doors. The frame on 1 side was fixed 20 cm above the floor, allowing sows to extend their limbs outside of the pen. The floor of the experimental pen was covered with the test floor, the pressure sensor maps (for description see below), and protective foils. Protective foils consisted of 2 layers of lorry tarp (PVC, 0.8 mm, 1.8 × 2.5 m) and 1 layer of a pool liner (PVC, 1.00 mm, 1.1 × 1.9 m). The test floor was covered with a first layer of lorry tarp on which the pressure sensor maps were laid. The sensor maps were next covered by the pool liner, and the second lorry tarp was overlaid to protect against contamination from feces and urine. This second layer of lorry tarp was stretched, resulting in a plane surface, which prevented sows from manipulating the experimental floor with their mouth and teeth.
Pressure Measurement System. Pressure was recorded with a 5400 NTL sensor map system (Tekscan Inc., Boston, MA) including 3 ultrathin (0.1 mm) flexible sensor maps, each with a measurement surface of 58 × 88 cm and 0.3 sensing point per square centimeter, resulting in an area of 2.89 cm² for each sensing point. A total measurement surface of 174 × 88 cm was achieved by fitting the 3 maps in parallel. The measures from the sensing points of the 3 sensor maps were combined using the 5400 NTL tool of the Tekscan software. The sensor map system was used with a sensitivity adjusted to the weights of sows. Before a new test floor was measured the sensor maps were pneumatically equilibrated with a hydraulic press (KNF Type, UN 811, KVP serial number 1/1242842, Tekscan Inc.) and a vacuum bag (Tekscan Inc.) according to the manufacturer's instruction (Tekscan Inc.). This equilibration was used to compensate possible changes in the sensitivity of sensors throughout the measurement period. The raw data were digitally measured in equidistant steps from 0 to 255. Raw digital data were converted into units of N/cm² using a 2-point linear calibration for each sensor map achieved by 2 weights of 68 and 133 kg and a basis of 131 × 201 mm. These weights were chosen as we assumed that they would match the weight of sows under different body parts. The 2-point calibration resulted in a range from 0 to 7 N/cm² at a resolution of 0.2 N/cm².

Data Recording. One day prior to the start of measurements sows were transferred to the experimental room where they were kept in the 4 pens described above. For pressure measurement a single sow from 1 of the 4 stalls in the experimental room was moved in the experimental pen where she stayed for a maximum of 1.5 h (maximal duration of an experiment). In order not to affect the lying behavior of the test sow, data recording was controlled and documented from an adjacent room by 2 infrared video cameras (VTC-E220IRP, Sanyo, Video AG, Ahrensburg, Germany) installed 1.50 m above the center of the experimental pen (camera 1) and on the side of the experimental pen at a horizontal distance of 0.80 m (camera 2). Video recordings were conducted with customized recording software (Friedrich-Loeffler-Institut, Celle, Germany) on an Asus PC (S-Presso Standard) and started as soon as a sow was confined in the experimental pen and ended when the sow left the experimental pen. Simultaneously, pressure load was continuously recorded with the measurement system software (BPMS Research 7.10, Tekscan Inc.) on a notebook (Acer Extensa 5635). Videos and pressure data were recorded with a time resolution of 20 frames/s. Thus, behavioral recordings from video and pressure recordings could be combined for analysis (Fig. 1).

If a sow did not lie down after 45 min, recording was terminated, and another sow was used. Sows that did not lie down in the first attempt were tested again later on the same day or the next day. When all sows of a subgroup were successfully recorded, a new subgroup was selected and housed in the experimental room. In total, measurements for each trial lasted about 14 d.

Analyzing Pressure Data. Pressure recordings were separately analyzed for sternal and half-recumbent lying positions following the descriptions by Ekkel et al. (2003). Because of an insufficient number of recordings it was not possible to analyze the data from fully recumbent lying.

For analysis, from each sow and each lying position a single data set (“screen print”) from the continuous recording of pressure data was selected when a sow did not change a given lying position within 15 s. This criterion was chosen to ensure a stable screen print for data analysis. Pressure data from sows lying in the sternal position were analyzed for the following body regions:
sternum, belly, and ham. For lying in the half-recumbent position we analyzed the same body regions and included the shoulder. Body regions were visually identified according to the sows’ anatomy and, if necessary, controlled by the respective video recording (Fig. 1).

Pressure data were converted to ASCII data, imported in Excel 2007, and analyzed with a custom-built macro that calculated pressure parameters as follows. First, sensing points with a value below 10% of the maximum value were rejected to separate signal from noise (Schrader and Hammerschmidt, 1997). Peak force (PF; in N/m²) was determined as the sensing point with the maximum pressure load. The contact area (CA; in cm²) of the body area with the floor was estimated by counting the number of sensing points with values above the noise threshold of 10% and multiplying by 2.89 cm², i.e., the area covered by a single sensing point.

**Statistical Analysis**

To determine the body regions with the highest pressure load, we calculated the median values of PF for the different body regions for the 2 lying positions. Subsequently, we analyzed the pressure parameters using a mixed-model ANOVA (MIXED procedure of SAS; Enterprise Guide, version 4.3., SAS Inst. Inc., Cary, NC). Residuals were tested for normal distribution (Kolmogorov-Smirnov test) and, in the case of nonnormal distribution, log₁₀ transformed. Floor type, weight class, and their interaction were included as fixed effects. Because not all sows showed both lying positions, the actual number of measures included in the analysis is given in the tables.

Body condition scores were not included in the analysis because 88% of sows had a BCS of 3 (normal), 5% had a score of 2 (thin), and 7% had a score of 4 (fat). In addition, BCS were strongly related to the weight of sows.

### RESULTS

**Pressure Load in Sternal Position**

The median values of PF in the sternal position were 1.62 N/cm² (25% quantile [Q1]: 1.17 N/cm², 50% quantile [Q2]: 2.10 N/cm²) on the sternum, 0.96 N/cm² (Q1: 0.74 N/cm², Q3: 1.19 N/cm²) on the belly, and 1.71 N/cm² (Q1: 1.33 N/cm², Q2: 2.10 N/cm²) on the ham. However, on the sternal PF showed the highest single maximum values, ranging up to 8.44 N/cm².

The PF on the sternum was affected both by floor type ($P = 0.0132$) and weight class ($P = 0.0012$; Table 1) but not by the interaction between floor type and weight class. Compared to CF the PF was lower on VSM ($P = 0.0012$) but did not differ between the other floors. Sows of weight class 1 showed lower PF compared to sows of weight class 2 ($P = 0.0007$) and weight class 3 ($P = 0.0021$).

The CA under the sternum differed between floors ($P = 0.0301$) and weight classes ($P < 0.0001$), and there was also an interaction between floor type and weight class ($P = 0.0002$). Compared to CF the CA was highest on SM ($P = 0.0156$) and VSM ($P = 0.0080$). Regarding weight, CA under the sternum was higher for weight class 3 compared to weight class 1 ($P < 0.0001$) and weight class 2 ($P = 0.0004$). Within weight class 1, the CA was higher on HM ($P = 0.0028$) and on VSM ($P = 0.0004$) in comparison to CF and higher on VSM ($P = 0.0112$) compared to SM. In weight class 2 the CA was only higher on SM ($P = 0.0045$) compared to CF. Within weight class 3 the CA was higher on CF ($P = 0.0074$) and SM ($P = 0.0173$) compared to HM.

**Pressure Load in Half-Recumbent Position**

The median values of PF across all floors were 1.29 N/cm² (Q1: 1.04 N/cm², Q3: 1.91 N/cm²) for the sternum, 1.14 N/cm² (Q1: 0.92 N/cm², Q3: 1.37 N/cm²) for the belly, and 1.71 N/cm² (Q1: 1.24 N/cm², Q3: 4 Weight class 1: 90 to 170 kg; weight class 2: 171 to 210 kg; weight class 3: 211 to 325 kg.

<table>
<thead>
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<th>Weight class</th>
<th>Floor$^2$</th>
<th>ANOVA$^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CF ($n = 27$)</td>
<td>HM ($n = 24$)</td>
</tr>
<tr>
<td>PF</td>
<td>1.91$^a$</td>
<td>1.47$^ab$</td>
</tr>
<tr>
<td>N/cm²</td>
<td>(1.57; 2.31)</td>
<td>(1.21; 1.80)</td>
</tr>
<tr>
<td>CA</td>
<td>190.09$^a$</td>
<td>221.97$^bc$</td>
</tr>
<tr>
<td>cm²</td>
<td>(171.92; 219.12)</td>
<td>(194.95; 252.74)</td>
</tr>
</tbody>
</table>

$^a$Least squares means within a row by floor or weight class with different superscripts differ ($P < 0.05$).

$^b$n = number of sows.

$^c$CF: concrete floor; HM: hard mat (4.0 mm penetration depth); SM: soft mat (14.6 mm penetration depth); VSM: very soft mat (43.0-mm penetration depth).

$^d$Weight class 1: 90 to 170 kg; weight class 2: 171 to 210 kg; weight class 3: 211 to 325 kg.

$^e$NS: not significant.

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**Table 1.** Least squares means and 95% confidence interval of peak force (PF) and contact area (CA) under the sternum of sows lying in the sternal position on different floors and for different weight classes.$^1$
2.58 N/cm²) for the ham, with 2.72 N/cm² (Q1: 2.09 N/cm², Q2: 3.81 N/cm²) being the highest median for the shoulder. The PF on the shoulder was affected by floor type ($P = 0.0388$) but not by weight class or the interaction between floor type and weight class. The PF was higher on CF ($P = 0.0128$) and HM ($P = 0.0113$) compared to VSM but did not differ for SM (Table 2).

The CA under the shoulder was only affected by weight class ($P = 0.0097$) and not by weight class or the interaction between floor type and weight class. The CA was lowest in weight class 1 compared to weight classes 2 ($P = 0.0055$) and 3 ($P = 0.0124$).

**DISCUSSION**

For the first time, this study analyzes the pressure load on different body regions in sows lying in different positions. We assumed that a minimum PF in combination with a maximum area of pressure distribution offers maximum lying comfort for sows. This was confirmed by our results showing that the softest mat reduced the pressure load the most when sows were lying in the sternal and half-recumbent positions. In addition, pressure load was affected by the weight of sows. Thus, our results yield important information about the design of floors for comfortable lying for sows.

When sows lay in the sternal position, a high PF was measured, particularly under the sternum. Baxter (1984) and Arey (1993) assumed that in the sternal position only 10%–20% of the pig’s total body surface area comes in contact with the floor; that is, the entire weight burden is on this comparably small body area. The sternum is a bony part of the thorax, and in comparison to the belly and the ham, which have proportions of 20%–40% fat and 40%–60% muscle content (Monziols et al., 2006), it is likely to be less protected against pressure load. Despite this different protection by muscle and fat tissue, PF on the sternum was as high as on the ham. Although there are no studies about possible damage or injuries to the sternum due to pressure load, the high PF on the sternum is likely to result in impaired resting comfort.

Only the VSM, with a penetration depth of 43 mm, led to a significant decrease of pressure load on the sternum, and with increasing weight class, PF on the sternum increased irrespective of floor type. Thus, only a VSM seems to be able to reduce PF on the sternum when sows lie in the sternal position. However, the area under the sternum with contact with the floor was higher for the SM and for the VSM in comparison to CF, which was most pronounced in weight class 1. As CA is also suggested as a parameter for lying comfort (Hänel et al., 1997), the SM already seems to result in improved lying comfort. The highest CA in sows in the heaviest weight class was expected because of their larger body size, which is related to BW.

In the half-recumbent position the highest PF was on the shoulder, and here the PF was nearly 2 times higher than on the sternum in the sternal position. Comparable to the sternum, the large tuber on the spine of pigs scapulae is sparsely covered with fat and muscle tissue (Monziols et al., 2006) and less protected against pressure load. Moreover, the shoulder blade is characterized by a tongue-shaped bony prominence, the tuber spina scapulae, and it is likely that pressure load is concentrated on this bone. Shoulder lesions such as decubitus ulcers are most often seen near the tuber of the scapular spine (Jensen, 2009). The PF on the shoulder could be reduced on the VSM compared to the HM and the CF, and it is well known that rubber mats support the healing of shoulder ulcerations (Zurbriggen, 2006). Furthermore, in a study by Tuyttens et al. (2008) gestating sows on a rubber mat lay up to 20% more often in the half-recumbent position and up to 25% less in the sternal position when compared to sows on CF. As lying in half recumbence is suggested to be more comfortable than lying in the sternal position, this may indicate that increased lying comfort can be accompanied by benefits for the health of sows.

Surprisingly, PF on the shoulder was not affected by the weight of sows. In addition, we also did not find an

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**Table 2. Least squares means and 95% confidence interval of peak force (PF) and contact area (CA) under the shoulder of sows lying in the half-recumbent position on different floors and for different weight classes.**

<table>
<thead>
<tr>
<th>Item</th>
<th>Floor</th>
<th>Weight class</th>
<th>ANOVA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(n = 25)</td>
<td>(n = 20)</td>
<td>(n = 21)</td>
</tr>
<tr>
<td>PF (N/cm²)</td>
<td>2.85-3.87</td>
<td>2.86-3.99</td>
<td>2.51-3.62</td>
</tr>
<tr>
<td>CA (cm²)</td>
<td>130.09-211.97</td>
<td>160.54-249.54</td>
<td>179.83-267.39</td>
</tr>
</tbody>
</table>

1 Least squares means and 95% confidence interval of peak force (PF) and contact area (CA) under the shoulder of sows lying in the half-recumbent position on different floors and for different weight classes. 

2 CF: concrete; HM: hard mat (4.0 mm penetration depth); SM: soft mat (14.6 mm penetration depth); VSM: very soft mat (43.0 mm penetration depth).

3 Weight class 1: 90 to 170 kg; weight class 2: 171 to 210 kg; weight class 3: 211 to 325 kg.

4NS: not significant.
effect of floor type on the size of CA under the shoulder. These findings possibly result from the high pressure load concentrated on the small-scale structure of the tuber scapulae, which does not enable an effective distribution of pressure load over a larger area. However, CA under the shoulder was lowest in the light-weight sows, probably because of the smaller size of the spina scapulae in the lighter and younger sows.

Although our results point out that only the softest mat used in our study might be able to significantly reduce the pressure load, the possibility that the protective foils that have to be used to protect the sensitive sensor maps might have masked any minor differences in the softness of the harder mats has to be taken into account. The VSM in our study had a penetration depth of 43 mm, and penetration depths of the other mats were distinctly lower (4.0 and 14.6 mm). Thus, using mats with a penetration depth in the range of 14 to 40 mm might also reduce pressure load. In addition, measurements of the pressure load should be combined with behavioral observations such as in preference tests to get information about the assessment of the comfort by the sows.

In conclusion, pressure measurements can add important information to behavioral studies by identifying body regions with the highest pressure loads during lying. Our results show that the pressure load on lying sows depends on the respective floor type and can differ between lying positions and the weight of sows. The most affected body parts are the sternum in the sternal lying position and the shoulder in the half-recumbent lying position. Hard rubber mats do not seem to offer high lying comfort with regard to pressure load.

**LITERATURE CITED**


