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Highlights

- Dynamic space utilization was estimated for lame and non-lame sows

- Laying-standing sequence was used to estimate dynamic space utilization

- On average, sows needed 1.2 ± 0.4 m^2 to lay and to stand-up

- Lameness did not affect the space used to lay, stand–up, or to turn around.

- Dynamic space utilization differed between measurement method used for estimation

DYNAMIC SPACE UTILIZATION FOR LAME AND NON-LAME GESTATING SOWS ESTIMATED BY THE LYING-STANDING SEQUENCE

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ABSTRACT

The objective of this study was to estimate the dynamic space utilization for lame and non-lame sows using their lying-standing postural sequence profile. Eighty-five sows (parity 0.9 ± 1.14; range 0 to 4) were used. Sows were moved to a pen on 30, 60 and 90 days of gestation and a ceiling mounted camera was installed above the pen to record one lying-standing event per sow. Observations ceased when the sow lied and stood, or 2.5 hours elapsed from recording commencement. Additionally, each sow was evaluated for walking lameness while moving from their gestation stall to the pen. Still frames were captured from the sows' lying and standing sequences and were combined into a single image and measured by counting pixels from contouring the sows' body (CONTOUR), overlaying a grid on the sow image and counting any square including any part of the sow (FULL-GRID) and only counting any square that was half full or more (HALF-GRID). The space utilized while turning around was calculated by measuring the sows' length from snout to the base of the tail and using that length as the diameter of a circle (D-PIVOT), or as the radius of a circle (R-PIVOT). Parity was re-classified as 0, 1, and 2+. Data were analyzed using mixed model methods with lameness, gestation day, and measuring method as fixed effects and sow as random effect. There were no observed differences in the dynamic space utilized to lie, stand or turn around between lame and non-lame sows ($P > 0.05$). On average, sows used 1.2 ± 0.47 m^2 to lie and 1.3 ± 0.46 m^2 to stand. There was no difference between the CONTOUR and HALF-GRID methods ($P > 0.05$); however, using the FULL-GRID sows required 0.3 m^2 more floor area to lie and stand compared with the other measuring methods ($P < 0.05$). Space used to turn around differed between measuring method ($P < 0.05$). Sows required 1.9 ± 0.18 m^2 for D-PIVOT and 7.3 ± 0.18 m^2 for R-PIVOT to turn around. Space utilized to lie-down and stand-up increased as gestation progressed ($P < 0.05$). Under the conditions of this study, lameness did not influence dynamic space utilization; however, lameness recorded was relatively mild and might not have been sufficiently severe to significantly affect the results. These results could be important in decision-making process for housing specifications regarding US sow gestation housing.

1. Introduction

Pig space allotments may impact their performance, health, and welfare. Space per pig (e.g. m^2/pig) or weight density (e.g. kg/m^2) are common ways to express space allowance (Gonyou et al., 2006). Several authors have proposed using the allometric equation $A = k \times BW^{0.667}$ to derive minimum space requirements over a wide weight range for swine (Baxter, 1984; Hurnik and Lewis; 1991); however, such approaches only measure static space requirements. Baxter and Schwaller (1983) described and visually depicted the sow's lying and standing sequences when housed in farrowing stalls and the authors attempted to calculate the dynamic space [i.e. space occupied by an animal plus the extra space needed to perform non-locomotor movements such as eating, drinking, lying and standing (Curtis, 1989)] required during such movements. However, the authors were unable to derive minimum space needs, mostly due to the space variation used during the different movements within the lying and standing sequence and suggested using sow body weight to calculate dynamic space needs. A similar approach was taken by Curtis et al. (1989) where the lactating sows' body weight was used to calculate static and dynamic space requirements. Results from this study indicated that sows required a physical space of 220.3 cm long by 86.4 cm wide and 99 cm high (Curtis et al., 1989).

However, factors other than body dimension or size may affect the requirements for sow space allotments. For instance, Anil et al., (2009) reported that lameness could present challenges to the sows' ability to perform normal behaviors. This observation was supported through studies that noted lame sows had a shorter latency to lie down than non-lame sows (Grégoire et al., 2013; Calderón Díaz et al., 2014a; 2014b; Roca et al., 2016). Lameness is the second leading reason for sows being prematurely culled from commercial swine breeding herds after reproductive problems (Pluym et al., 2011). Lameness is an economical (Dijkhuisen et al., 1989; Anil et al., 2009; Rodríguez et al., 2011), worker morale (Bell and Main, 2011) and animal welfare issue (Dewey et al., 1993; Rowles, 2001; Anil et al., 2009). Currently, there

is very little information in the scientific literature about lameness etiology and severity on the dynamic space used during the sow's lying-standing sequence. The sow has physically and physiologically changed over the past 30-years through genetic improvement for reproductive traits (Foxcroft, 2012) and these improvements may have affected the 3-dimensional space utilization when making postural adjustments. Genetic differences lead to differences in space requirements (McGlone et al., 2004; Anil et al., 2002). In addition, Cai et al., (2008) have noted differences in genetic lines for high or low Residual Feed Intake (RFI). Understanding how sows utilize their dynamic space could assist animal scientists, agricultural engineers and veterinarians when designing housing and subsequent space allocations. Therefore, the objectives of this study were to (1) calculate the dynamic space requirements for commercial multiparous lame and non-lame sows determined by their lying-standing postural sequence profile, (2) calculate the space required to turn around for lame and non-lame sows and (3) identify differences in dynamic space requirements and space utilized when turning around between sow's divergently selected for residual feed intake (RFI).

2. Materials and methods

2.1. Care and Use of Animals

This study was approved by the Iowa State University Institutional Animal Care and Use Committee # 6-15-8035-S, and it was conducted in accordance with the Guide for the Care and Use of Agricultural Animals in Research and Teaching as issued by the American Federation of Animal Science Societies (FASS, 2010). The study was conducted at the Lauren Christian Swine Research Center experimental farm, Madrid, IA. This was an observational study whereby sows were managed as per usual practice on the farm. None of the authors had input in daily management of the sows and thus, farm staff were responsible for performing overall health checks as per routine practice.

Eighty-five females (median parity 2.5; range 0 to 4) were included in this study. Gilts used represented the entire population from the 10th generation of Yorkshire pigs divergently selected for Residual feed intake (RFI; n = 26 Low RFI and n = 20 High RFI) at Iowa State University (Cai et al., 2008). The remaining 39 multiparous sows were cross-bred Large White $\times$ Landrace. Hereafter, all animals will be referred to as sows. Sows were individually housed in gestation stalls (2.61 $\times$ 0.76 m)

with fully slatted concrete flooring until moved to farrowing crates approximately four days prior to parturition. The gestation barn was a double curtain-sided, naturally ventilated facility. Additional stir fans on opposite ends of the barn assisted with animal cooling in the summer months and two heaters at opposite ends of the barn provided heat in the winter. Sows were manually fed once daily a gestation diet that met or exceeded NRC requirements (NRC, 2012) and they had *ad libitum* access to water in troughs at the front of each gestation stall.

2.2. Measurements

All space and lameness measures were recorded at approximately 30, 60 and 90 days of gestation. Sows were individually moved to one of two gestation pens (2.56 m W $\times$ 2.43 m L and 2.17 m W $\times$ 2.43 m L) available at the farm where video recording occurred. The flooring was partially slatted concrete (2.6 m^2 solid flooring and 2.6 m^2 slatted flooring).

2.2.1. Lameness

While moving to the gestation pen, after allowance for stiffness to subside, sows were visually scored for walking lameness using a 3-point scale adapted from the lameness scoring system developed by Main et al., (2000) where 1 = non-lame (i.e. sow appears bright, alert and responsive, the sow stands squarely on all four legs and has even strides); 2 = mildly lame [i.e. the sow appears bright but may be less responsive (may remain lying or dog sitting before eventually rising), she may limp and have shortened strides]; and 3 = severely lame (i.e. the sow is unwilling to leave a familiar environment, she may not bear weight on affected limb and has shortened stride. If a sow received a lameness score of 2 or 3, the affected leg was recorded).

2.2.2. Behavioral Observations

In each gestation pen, one video camera (GoPro Hero, GoPro Inc., San Mateo, CA, USA) was positioned on the ceiling 2.9 m or 2.2 m above the sow for the large and small pen respectively. Cameras were set at 1080p and 30FPS shutter speed. Images of the sows were video recorded between 8:00 AM and 5:00 PM. Video recording finished once the sow had either performed one lying and one standing sequence, or 2.5 h of continuous video had been collected.

Lying was defined as three sequence movements previously described by Baxter and Schwaller (1983) where "(i) the sow drops into a kneeling position, then (ii) the sow rotates the upper part of her body to bring a shoulder and side of the head to rest on to the floor and finally, (iii) the sow lowers her hindquarters and finishes in either ventral or lateral recumbency." *Standing* was classified according to the sequence of movements described by Baxter (1984) whereby, "(i) the sow positions her body onto her sternum with her front legs folded beneath her body and rises to a sitting position then, (ii) the sow starts to lift her hindquarters straight off the floor to achieve full standing position."

Video recordings were separated into their single frame images using AVCutty software, (AVCutty v3.5, Andreas von Damaros, Krefeld, Germany, www.avcutty.de). Two to five still images were selected by a single trained observer for each sow whilst performing the lying and standing sequence. The still images were undistorted using GML Camera Calibration toolbox (Vezhnevets et al., 2001, GML C++ Camera Calibration Toolbox, 2011; Figure 1). Undistorted images were processed in Adobe Photoshop Elements 14 (Adobe Systems Incorporated, San Jose, California, United States). Processing involved selection and layering each sow movement during the lying and standing sequences into one image using anchor points such as the gating bars and floor slats used in each pen to ensure proper placement (Figure 2).

2.2.3. *Dynamic Space Utilization*

Dynamic space utilized to lie and stand as well as the space used to turn around were calculated for each sow. All image analyses were completed using Photoshop Elements 14. Three different methods were used to calculate dynamic lying and standing space utilization.

First, the default grid view was placed over the image and grid squares where at least half of the area (HALF-GRID) was taken up by the sow's body were manually counted. In a similar way, the grid squares were counted if any portion of the sows' body was seen within a square (FULL-GRID). The area of the grid squares was measured by a pixel comparison in a square to pixels of a clipboard with known

area. The area taken up by the sow's body was obtained by multiplying the number of squares counted by the corresponding square area (Figure 3). For the third method, the quick select pixel tool was used to outline the sow (CONTOUR) against the background and the pixels were counted using the 'Histogram' function. Pixel measurement was compared to the same clipboard (Figure 4).

To measure the space used to turn around two different methods were used to calculate sow area in the form of a circle. First, an overhead image of each sow while standing straight (no curve or bend in the spine) was taken. Using ImageJ software, (ImageJ, National Institute of Health, Behesda, MD, USA) the sow's body length was measured from the tip of the snout to the base of the tail and the pixel number was compared in meters to the known pen length (i.e. 2.43 m). The length of the sow was considered the diameter of a circle and area (D-PIVOT) calculated by

$$D - PIVOT = \pi(0.5r)^2;$$

where r = sow body length.

For the second method, the same images for each sow were used and body length was considered the radius of a circle and area (R-PIVOT) calculated by

$$R - PIVOT = \pi r^2$$

where r = sow body length (Figure 5).

Statistical analysis

Each sow was considered the experimental unit. Only one sow was classified as having a lameness score 3 during the entire trial; thus, lameness was re-classified as non-lame (score = 1) and lame (score = $\geq$ 2). Twenty-eight sows were removed from the trial. Four sows were moved to the Veterinary Laboratory at Iowa State University before completing their pregnancies because they were diagnosed as Severe Combined Immuno-Deficiency (SCID) carrier mothers and utilized in another study. Twenty-four sows were not pregnant (Table 1). Pregnancy determination was done per farm protocol, and when an animal was deemed open she was immediately removed from the study. Rear leg lameness accounted for ninety-eight percent of all lameness in the present study. Only one female (parity 0, High RFI line) was classified as having a lameness score of 3 and was removed from the analysis.

Models included lameness score, area measuring method and gestation day as fixed effects. Sow was included as a random effect. Genetic line was confounded within parity and therefore it was not used as predictor variable in the models. Residuals were evaluated for normality using the Shapiro-Wilk test and examining the normal plot. Data were analyzed using mixed model equation methods in (PROC MIXED, SAS v9.4, SAS Inst. Inc., Cary, NC).

To investigate possible differences in dynamic space utilization between RFI lines, only data collected from gilts were used for this analysis. Data was analyzed as previously described with the difference that models included RFI line instead of parity. In all analyses, lameness score was included in the model irrespective of its *P* value. Statistical differences and trends were reported when model source of variation was $P \leq 0.05$ and $P \leq 0.10$, respectively. When a main effect was a significant source of variation, levels from each main effect were separated using the PDIFF option. A Tukey-Kramer adjustment was performed to account for multiple comparisons. Results are reported as least square means ± SEM.

Test-retest reliability for each of the methods used was calculated using intraclass correlation coefficients (ICC; Shrout and Fleiss; 1979). Test-retest reflects the variation in repeated measurements taken on the same subject under the same conditions (Koo and Li, 2016). ICC was calculated as

$$ICC = \frac{\sigma_\alpha^2}{\sigma_\alpha^2 + \sigma_\epsilon^2}$$

where σ_α^2 is the variance between measurements and σ_ϵ^2 is the residual variance (Barlett et al., 2008).

3. Results

3.1. Reliability results

ICC coefficients for the different measurement methods were moderate and are presented in Table 2.

3.2. Dynamic Space Utilized to Lie Down and to Stand Up

On average, sows used 1.26 ± 0.4 m^2 to lie and 1.35 ± 0.5 m^2 to stand. There were no observed differences in the dynamic space that sows utilized to perform the lying or standing sequence when comparing lame and non-lame sows ($P > 0.05$). Method used to calculate space utilization was a significant source of variation. There was no difference between the CONTOUR and HALF-GRID measuring methods ($P > 0.05$) however, when using the FULL-GRID measuring method sows utilized 0.3 m^2 more to lie and to stand when compared to the other two measuring methods ($P < 0.05$; Table 2). The space sows used to lie and stand increased as gestation progressed to 90 days ($P < 0.05$; Table 2). When comparing dynamic space utilization between the two RFI lines, sows from the Low RFI line used 0.2 m^2 more to stand compared with sows from the High RFI line (1.25 vs 1.06 ± 0.05 m^2, respectively; $P < 0.05$). There was no observed genetic line difference (High RFI or Low RFI) when evaluating the dynamic space sows needed while lying (1.12 vs 1.03 ± 0.05 m^2, respectively; $P > 0.05$).

3.3. Space Utilized to Turn Around

No dynamic space or gestation day differences were observed when evaluating the area lame and non-lame sows used to perform the turnaround sequence ($P > 0.05$). Method used to calculate the space sows utilized while turning around was a significant source of variation as more space was needed when using the R-Pivot method ($P < 0.05$; Table 2). Further, there was no difference between the two RFI lines when evaluating the space the sows used to turn around (4.1 ± 0.17 for Low RFI line and 4.0 ± 0.21 m^2 for High RFI line; $P > 0.05$).

4. Discussion

4.1. Dynamic Space Utilized to Lie Down and to Stand Up

To our knowledge this is the first reported effort where gilt and sow dynamic space utilization has been calculated directly from the digital images recorded when breeding herd females are performing the lying-standing process. Previous reports from the scientific literature derived dynamic space needs using the k-value equation (i.e. $A = 0.047BW^{0.66}$) that was developed by Petherick (1983) where sow body

weight was used to calculate the minimum space for an animal. The *k*-value method assumes that animals maintain the same general shape regardless of body weight and, therefore, it could be considered an accurate estimation tool. However, the *k*-value estimation only considers the static space measurement and thus, does not include the space an animal may require for movements. Baxter and Schwaller (1983) attempted to calculate the dynamic space required during the lying-standing sequence, but the authors were unable to derive minimum spaces largely due to the variation in space used during the different movements and suggested using body weight to calculate dynamic space. However, measurements were obtained from a very limited sample size (n = 5 sows) and all sows used had very similar body weight. However, Baxter and Schwaller (1983) suggested that a minimum of 1.89 m^2 would allow sufficient space for standing and lying.

Using information regarding the variation in minimal space needed to move forward and for movement to the side during the standing sequence reported by Baxter and Schwaller (1983), Petherick (2007) estimated a static space requirement of $0.046BW^{0.66}$, for a sow to lie in lateral recumbency. A similar approach was taken by Curtis et al., (1989) where the sow body weight was used to calculate static and dynamic space requirements for sows in late gestation and weaned sows. Curtis et al., (1989) reported a minimum of 1.4 m^2 (1.91 L × 0.74 W) for a 150 kg sow and 2.11 m^2 (2.32 L × 0.91 W) for a 300 kg sow. These dynamic space needs are greater than those observed in the present study. However, Curtis et al., (1989) based their calculation on the 95th percentile static requirements. Furthermore, the length measurement used was recorded on d 21 post-farrowing while the width measurement was recorded between days 107 and 110 of gestation. Results from the present study are similar to the static space requirements for lying under the European legislation (EU Council Directive 2008/120/EC; 0.95 m^2 for gilts and 1.3 m^2 for older sows housed in groups).

We hypothesized that lame sows would need greater dynamic space as Bonde et al., (2004) reported that severely lame sows displayed uncontrolled movements when lying in the farrowing stall and Calderón Díaz et al., (2014a, 2014b) reported that severely lame lactating sows had a shorter latency to lie down. Similarly, Grégoire et al., (2013) noted that lameness has potential to affect the transition from lying to

standing in both group and stall housed sows; however, they were unable to efficiently incite sows to rise to measure the changes in that transition that may have been associated with lameness. However, under the conditions observed in the present study, lameness did not affect the dynamic space used by sows to perform the lying and standing sequence. It is important to note that lameness observed in the present study was mild and only one sow received a lameness score 3 and thus, sows might not have been sufficiently severe to significantly affect the results. Differences in the findings between studies could have resulted from the stage of production that sows were in (e.g. lactation stage was not consistent across all the studies whereas only gestating sows were observed for the present study). Also, types of production (e.g. group housing vs. stall housing), and/or flooring type on which sows were recorded. Void ratios are greater in the flooring used in farrowing stalls than in flooring used in gestation stalls/pens and large void ratios increase pressure applied to the sows' toes (Anil et al., 2007) and provide poorer grip which could exacerbate lameness effects so that a sow cannot control body movements when lying and standing and increase the space the sow requires to perform those movements.

The method used to measure the sows' area has an impact on the results. The FULL-GRID method overestimates the CONTOUR and HALF-GRID methods by approximately 0.3 m^2. In regards to estimating the minimum dynamic space utilized by sows while standing and lying, using either the CONTOUR or HALF-GRID methodologies produce similar results, which are within the static space requirements for sows lying that have been outlined under the European legislation (EU Council Directive 2008/120/EC; 0.95 m^2 for gilts and 1.3 m^2 for older sows housed in groups). The overestimation when using the FULL-GRID method stems from including the sows' extremities, such as the tail and ears, which extended to multiple grid squares beyond the central mass of the sow's body. When measuring lesion scores, previous work by Anil et al., (2002) suggests that high tail maneuverability allows for avoiding contact with the gestation or farrowing stall that would cause lesions. Using this thought process, it can be proposed that the HALF-GRID or CONTOUR methods are likely more accurate estimations when determining minimum dynamic space needs as the tail and ears that would be included in many FULL-GRID overestimations can be considered maneuverable enough to fit within the confines of the sow's central body mass.

However, it is important to note that the reliability of the three methods used was moderate and results were similar between them. In this study, the observed moderate reliability values are likely due to the fact that not all sows have complete records for the three observation points. Also, the number of pictures used for each sow to measure dynamic space requirements varied as sows did not always follow the 3-step lying/standing sequences. In fact, in a separate study using the same sows we characterized eight different movement combinations to lay-down and 5 different movement combinations to stand-up (Mumm et al., *in preparation*). This suggests that, perhaps, there is no "standard" lying-down or standing-up sequence as the same sow did not always lie or stand in the same manner because sows have *personal* idiosyncrasies Baxter and Schwaller (1983). Future methodologies developed to measure dynamic space requirement should consider the variation in the sequences and try to quantify the minimum dynamic space requirements that would facilitate the most complex combinations.

Previous space results report increased space as animals age. McGlone et al., (2004) reported that sow body depth increased by 1.2 mm/day m from day 23 to 115 of gestation, but these measurements were static space requirements. Differences in the space used to stand were observed between RFI lines; however, in this portion of the study, only gilts were used. The biological relevance of this finding is unclear and requires more investigation.

4.2. Space Uitlized to Turn Around

Sows will exercise their ability to turn around if it is available to them (McFarlane et al., 1988; Bøe et al., 2011), and will even show a preference toward a wider stall that will allow them to turn around before and after farrowing (Phillips et al., 1992). The present study reports either 1.9 m^2 or 7.17 m^2 for an uninterrupted area utilized to turn around based on mathematical equations that used the sows' body length to pivot. This contrasts with other studies where direct sow observation has been used to determine the area needed for sows to turn around (Bøe et al., 2011; McFarlane et al., 1988). Bøe et al., (2011) calculated minimum pen widths at which a sow would turn around. The authors reported that sows turned around at will until the point when the pen width decreased to half that of their body length, 1.57 m on average. According to Anil et al., (2002), average gestation stall dimensions are 1.82 m L $\times$ 0.59 m W

(1.06 m^2 for total sow area). This number is nearly 1 m^2 smaller than the most conservative measurement these authors found for a sow to turn around, and would indicate that sows housed in commercial gestation stalls in the U.S. would be unable to turn around even if they preferred to.

McFarlane et al., (1988) reported that as gestation stall width decreased from 61 cm to 56 cm, turning frequency decreased by more than 30 %. The physical restriction reported from the latter study does not account for individual sow length as the present study offers, and it is inferred that the sow is required to exhibit some margin of flexibility to turn completely around. The current study suggests that a greater area is needed for a sow to turn around, perhaps due to the calculation method as the authors did not consider the flexibility of the sow's spine. However, reliability was moderate for the two measuring methods used and our results should be viewed with caution.

Regardless of calculations, the area a sow requires to turn around impacts stocking density and current production systems greatly. Harris et al., (2006) note that gilts housed in groups with free access stalls for feeding only spent 23% of their time standing at week 4 of gestation and only 15% during week 13. Combined with Ekkel et al. (2003) which notes pigs weighing more than 25 kg prefer to lay in contact with penmates for most of the day, the authors assume that in a group housing scenario, not every sow will need to use the amount of dynamic space calculated as many females will be resting in positions that call for static measurements, and many will be in contact with one another. Thus, our minimum dynamic space utilization can be used cautiously and combined with static measurements to identify stocking density and pen numbers in group housing situations.

5. Conclusion

Under the conditions of this study, lameness did not influence dynamic space requirements. However, an insufficient number of sows with severe lameness were identified to be included in the present study, thus, lameness might not have been severe enough to affect the studied traits. Current technology offers new ways to measure dynamic space requirements for sows and it could be used as an effective tool when designing new gestation sow housing facilities or retrofitting existing structures.

Results from this study could be important as a baseline for determining the minimum dynamic space requirements when estimating space needs for gestation sow housing systems in the USA.

Acknowledgements

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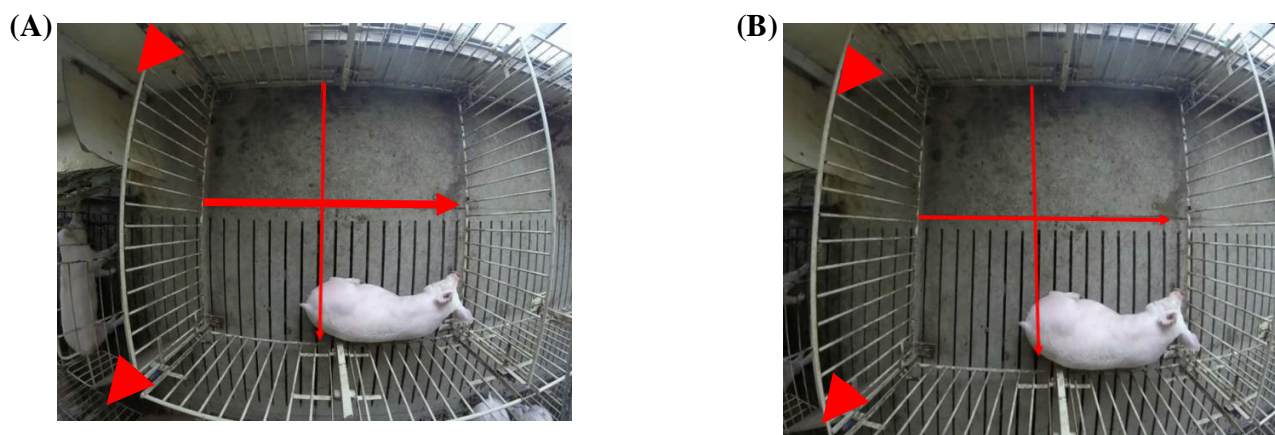
Figure 1. Top view images of sows' video recorded for one lying-down-standing-up event at approximately 30, 60 and 90 days of gestation in a study estimating dynamic space utilization to lie-down, stand-up and turn around in lame and non-lame multiparous commercial sows. (**A**) Distorted image makes no correction for curvature of camera lens; (**B**) Raw images have been corrected for inaccuracies resulting from the curvature of the camera lens
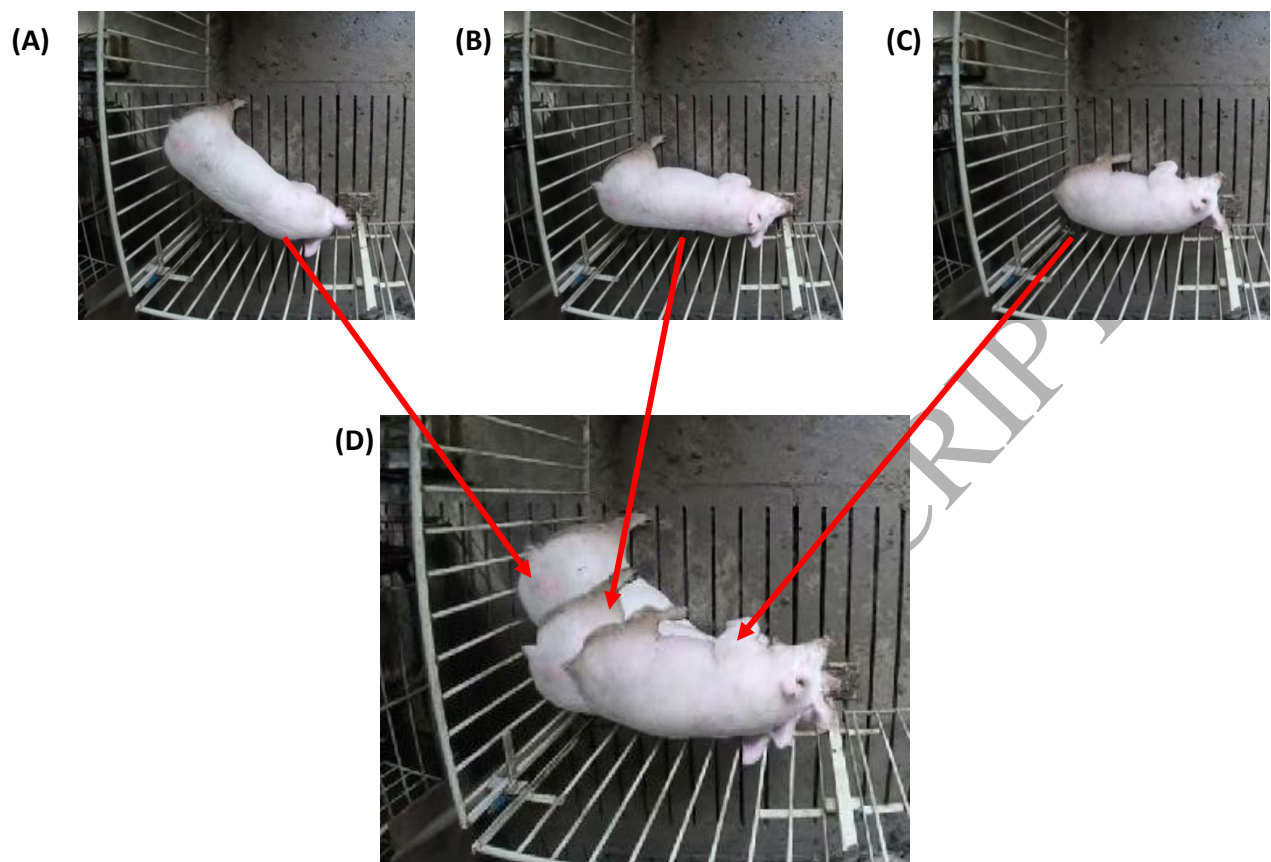
Figure 2. Layering of images according to the lying down sequence of multiparous sows video recorded for one lying-down-standing-up event at approximately 30, 60 and 90 days of gestation in a study estimating dynamic space utilization to lie-down, stand-up and turn around in lame and non-lame multiparous commercial sows. The lying down sequence was classified as described by Baxter and Schwaller (1983) where **(A)** sow drops into a kneeling position, **(B)** then the sow rotates the upper part of her body to bring a shoulder and side of the head to rest on to the floor and **(C)** finally, the sow lowers her hindquarters and finishes in either ventral or lateral recumbency. (**D**) is the combination of figures 2A, 2B and 2C using Photoshop Elements 14.
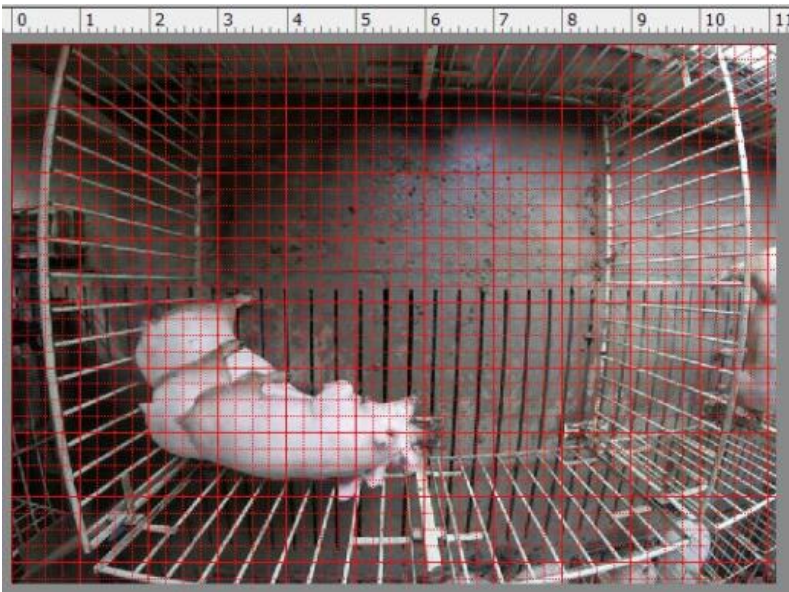
Figure 3. Overlaying a grid on the sow image to calculate the dynamic space utilization to lie down and to stand up at approximately 30, 60 and 90 days of gestation in lame and non-lame multiparous commercial sows. Two methods were used using the default grid view in Photoshop Elements 14. First, grid squares that where at least half of the area (HALF-GRID) was taken up by the sow were manually counted. Resulting area for a sow to lie and stand using this method was 1.10 ± 0.05 and 1.15 ± 0.05 respectively. In a similar way, the grid squares were counted if any part of the sow body was seen in them (FULL-GRID). Resulting area for a sow to lie and stand using this method was 1.41 ± 0.05 and 1.51 ± 0.05 m^2 respectively.

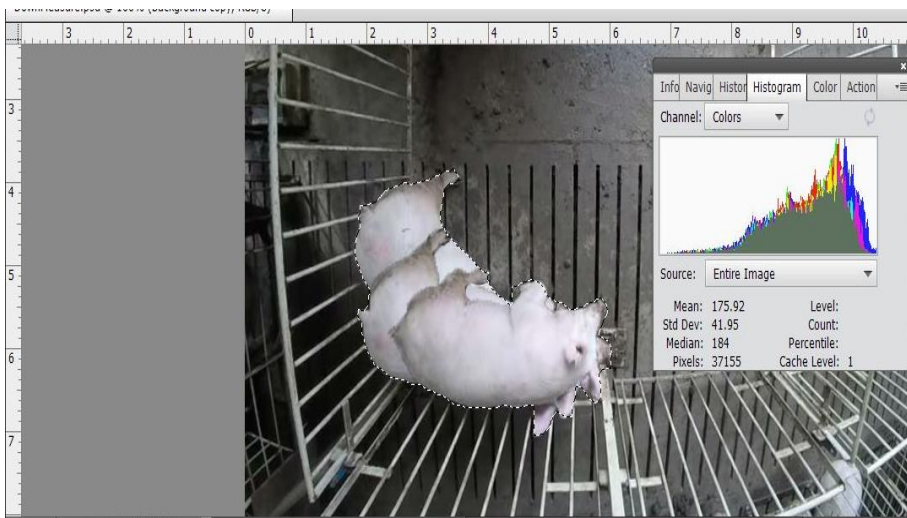**Figure 4.** Drawing and measurement of the sow outline (CONTOUR method) to calculate the dynamic space utilization to lie down and to stand up at approximately 30, 60, and 90 days of gestation for lame and non-lame multiparous commercial sows using Photoshop Elements 14. The average area used by a sow to lie and stand using this calculation method was 1.13 ± 0.04 and 1.19 ± 0.05 m^2 respectively.

Figure 5. Measurements of the dynamic space utilized to turn around in lame and non-lame multiparous commercial sows at approximately 30, 60 and 90 days of gestation. First, an image of each sow while standing straight was taken. Using ImageJ software (ImageJ, National Institute of Health, Behesda, MD, USA) the length of the sow was measured from the tip of the snout to the base of the tail and the number of pixels was compared in meters to the known length measurement of the pen (i.e. 2.43 m). The length of the sow was considered the diameter of a circle and area calculated by $\pi \times 0.5x^2$ where x= sow body length (D-PIVOT). For the second method, the same image of the sow standing straight was

used but the whole length of the sow was considered the radius of a circle and area calculated by πr^2 where r = sow body length (R-Pivot). The respective areas calculated for a sow to turn around for the D- and R- pivot are 1.90 ± 0.12 and $7.17 \pm 0.15 \text{ m}^2$.

Table 1. Descriptive statistics for Lame and Non-lame sows that were recorded for lying and standing observations on gestation days 30 60 and 90.

Gestation day	No. sows video recorded[a]	No. of lame sows[b]	No. sows that laid down and stood up[c]	No. of lame sows that laid down and stood up[d]
30 d	85	34	61	25
60 d	80	44	53	36
90 d	57	22	45	15

[a] Number of sows that remained pregnant and were video recorded at day 30, 60 and 90 of gestation.
[b] Number of sows that were classified as lame from the total number video recorded per observation.
[c] Total number of sows that performed the lying and standing behavior at gestation day 30, 60 and 90.
[d] Total number of lame sows that performed the lying and standing behavior at gestation day 30, 60 and 90.

Table 2. Intra-class correlation coefficients (±SE) for the repeatability of each measurement method used while sows lie and stand.

	ICC[1] Lying down[2]	ICC Standing up[3]	ICC Turn around
CONTOUR[4]	0.57	0.61	
FULL-GRID[5]	0.58	0.55	
HALF-GRID[6]	0.55	0.59	
D-PIVOT[7]			0.52
R-PIVOT[8]			0.53

[1] calculated as $ICC = \frac{\sigma_\alpha^2}{\sigma_\alpha^2 + \sigma_\epsilon^2}$

[2]The movement from a standing position to lying.

[3] The movement from the lying position to standing.

[4] Contour method was obtained by tracing the outline of the sow and measuring the pixels compared to a known area.

[5] FULL-GRID; method where each grid square was counted if it included any part of the sow.

[6]HALF-GRID: method where each grid square was counted if it was half or more filled by any part of the sow.

[7] Pivot method assuming using half the length of the sows body from snout to tail ($\pi \times 0.5x^2$) where x is body length of the sow.

[8] Pivot method using the entire body length of sow as the radius of a circle πr^2 where r is body length of the sow.

Table 3. Dynamic space utilization (least square means ± SE) for lame and non-lame multiparous sows at approximately 30, 60 and 90 days of gestation to lie down, stand up and turn around.

Variables	Laying down area, m²		Standing up area, m²		Turn around area, m²	
	LS Means	SEM	LS Means	SEM	LS Means	SEM
Lameness						
Non-lame	1.21[a]	±0.05	1.27[a]	±0.05	4.53[a]	±0.19
Lame	1.19[a]	±0.05	1.30[a]	±0.05	4.65[a]	±0.19
Gestation Day						
30d	1.13[a]	±0.04	1.24[a]	±0.05	4.70[a]	±0.19
60d	1.22[a,b]	±0.05	1.25[a]	±0.05	4.50[a]	±0.20
90d	1.26[b]	±0.05	1.37[b]	±0.05	4.57[a]	±0.21
Measuring method						
CONTOUR[1]	1.13[a]	±0.05	1.20[a]	±0.05	-	-
FULL-GRID[2]	1.41[b]	±0.05	1.51[b]	±0.05	-	-
HALF-GRID[3]	1.08[a]	±0.05	1.15[a]	±0.05	-	-
D-PIVOT[4]	-	-	-	-	1.92[a]	±0.18
R-PIVOT[5]	-	-	-	-	7.26[b]	±0.18

[1] Contour method was obtained by tracing the outline of the sow and measuring the pixels compared to a known area.

[2] FULL-GRID; method where each grid square was counted if it included any part of the sow.

[3] HALF-GRID: method where each grid square was counted if it was half or more filled by any part of the sow.

[4] Pivot method assuming using half the length of the sows body from snout to tail ($\pi \times 0.5x^2$) where x is body length of the sow.

[5] Pivot method using the entire body length of sow as the radius of a circle πr^2 where r is body length of the sow.

[a,b] Within each column, significant differences between levels of each predictor variable; $P < 0.05$.