Title: Dynamic space requirements for non-lame and lame sows determined by lying-standing sequence profile – NPB# 15 -004

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Industry Summary:

Understanding how sows utilize their dynamic space envelope could assist animal scientists, agricultural engineers and veterinarians when considering the dynamic space needs in gestation housing. The primary goal of this project was to estimate the area utilized by multiparous lame and non-lame gestating sows as they lie down and stand up. A secondary objective was to characterize the postures and movements of the lying down and standing up postural sequences, and to identify possible differences between lame and non-lame sows. A third objective was to identify other leg risk factors for lameness in multiparous sows. Eighty-five multiparous sows were scored for walking lameness on a 3-point scale (1=sound, 2=mildly lame, 3=severely lame) when moved from their home gestation stall to a testing pen. Limb lesions such as callus, swellings and wounds were scored in the front and rear legs according to severity. Sows were video recorded for one lying-standing event at 30 60 and 90 days of gestation. The digital video camera was affixed on the ceiling, over the testing and the sow was filmed dorsally until she laid down and stood up one time, or if 2.5 hours elapsed from the start of the recording. The lying and standing behavioral sequence were cut from the video as still frames. Images were combined into a single image and measured by two different methods; either counting the number of pixels on the contour of the sows' body or by overlaying a grid on the image of the sow. On the same gestation days, a second video recorded the sows' profile in a gestation stall. From this secondary video, sow postures and movements that occurred during the lying-standing sequence were identified and the time taken to transition between movements was recorded. Furthermore, joint angulation at the knee, hock, front and rear pasterns were measured using digital images extracted from this secondary video on gilts.

Goal One: To estimate the area utilized by multiparous lame and non-lame gestation sows as they lie down and stand up: On average, sows used 1.2 ± 0.4 m^2 to lie down and to stand up. There were no observed differences in the dynamic space required to perform the lying-down or standing-up sequence between lame

and non-lame sows. Additionally, there was no difference in the space required between the two measuring methods used (i.e. either counting the number of pixels on the contour of the sows' body or by overlaying a grid on the image of the sow). The dynamic space requirements found in this study are, smaller than those reported previously; however, they are similar to the static space lying requirements outlined in the European legislation (EU Council Directive 2008/120/EC). Additionally, the sows' dynamic space requirement found in this study could be accommodated in a gestation stall. It is important to note that this does not include space needed to turn around or to move forward or backwards. We hypothesized that lame sows would need a greater dynamic space requirement because previous research has concluded that severely lame sows show uncontrolled movements while lying down. However, under the conditions of this study, lameness did not affect the dynamic space needed to lie-down and stand-up.

Goal Two: To characterize the postures and movements of the lying down and standing up postural sequences, and to identify possible differences between lame and non-lame sows: Lameness did not affect the time needed to perform the different movements of the lying-standing process. While lying, on average, sows took 13.9 seconds from kneeling to rotating their shoulders, 7.7 seconds from rotating their shoulders to lower their hindquarters and 20 seconds to complete the lying down sequence. While standing, on average, sows took 8 seconds from folding their legs to sitting, 6.9 seconds from sitting to standing and 9.8 seconds to complete the standing sequence. There were no differences between lame and non-lame sows in the movements performed In both the lying down and standing up sequences. It is important to note, that lameness was categorized as "mild" with only one sow being classified as "severe". Nonetheless, results from this study could be important in the decision making process for new specifications regarding space needs for gestation sow housing in the USA.

Goal three: To identify other leg and toe and dew claw risk factors for non-lame and lame multiparous sows. Limb lesions such as calluses, swellings and wounds were not associated with the risk of lameness. Knee, front and rear pasterns' joint angles were wider in lame gilts indicating a greater effort of the gilt to balance her body due to the discomfort she might be experiencing.

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Keywords:

Dynamic space requirements, joint angles, lameness, lying down postures, standing up postures, sows

Scientific Abstract:

The primary objective of this project was to determine the dynamic space requirements during a lying-standing postural sequence for lame and non-lame sows. A secondary objective was to characterize the postures and movements for the lying down sequence in multiparous sows and to identify possible lying sequence differences between lame and sound sows. A third objective was to identify other leg risk factors for lameness in multiparous sows. A total of 85 multiparous sows were used. Each sow was evaluated for walking lameness between their gestation stall to a pen using a 3-point scale (1 = normal to 3 = severely lame). Also, limb lesions such as callus, swellings and wounds were scored in the front and rear legs according to severity. Individual 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 down-standing up event per sow. Observations ceased when the sow laid-down and stood-up or if 2.5 hours elapsed from recording commencement. Still frames of lying-down and standing-up sequences were combined into a single image and measured in Adobe Photoshop Elements by either counting pixels by contouring the sows' body or by overlaying a grid on the sow image. A second video of the sows' profile while standing in a gestation stall was collected on the same gestation days. From this video, postures and movements that occurred during the lying-standing sequence were identified. Time (seconds) from kneeling to shoulder rotation (KSR), shoulder rotation to lying (SRHQ) and total time to lie down (TLIE) were determined. In addition, latency to lie down (LATENCY; minutes) and number of attempts (ATTEMPTS) to successfully lie down were recorded. Time (seconds) to stand up was defined as the first leg fold to sit (TLS), time from sit to rise (TSR), and total time to rise (TRISE) were recorded from the standing up sequence. Furthermore, joint angulation at the knee, hock, front and rear pasterns were measured using digital images extracted from this secondary video only on first parity sows. Data was analyzed using mixed model equations. Lameness was re-classified as non-lame (score 1) and lame (scores ≥ 2) and parity was re-classified as 0, 1 and 2+. Data were analyzed using mixed model equations methods. On average, sows used 1.2 ± 0.4 m^2 to lie down and to stand up and there was no difference in the space required between the two measuring methods used (*P* > 0.05). Space required to lie-down and stand-up increased as gestation progressed (*P* < 0.05). Lameness was not a significant source of variation for any of the traits evaluated in this study (*P* > 0.05). On average, sows took 13.9 seconds for KSR, 7.7 seconds for SRHQ, 20.5 seconds for TLIE and 66.1 minutes for LATENCY. Furthermore, sows took 8.0 seconds for TLS, 6.9 sec for TSR, and 9.8 seconds for TRISE. Lame sows tended to take longer during KSR (15.5 vs. 11.9 ± 1.59 seconds for lame and sound sows, respectively; *P* = 0.08), and to spend less time standing (54.1 vs. 69.8 ± 6.20 minutes for lame and sound sows, respectively; *P* = 0.06) compared with sound sows. Additionally, lame sows tended to be more likely to sit while transitioning from lying to standing compared with sound sows (*P* = 0.07). Gestation day and parity were not associated with the time taken for the different movements in the lying down sequence (P > 0.05). There were no significant associations between gestation day, lameness status or parity and attempts to lie down. Sows parity 1 had greater TLS compared with gilts (20.9 vs. 4.7 ± 3.01 seconds; *P* < 0.05) and sows parity 2+ (20.9 vs. 5.5 ± 3.62 seconds; *P* <0.05). Parity 1 sows tended (*P* = 0.09) to take 8.1- and 6.7 seconds more for TRISE than gilts and 2+ sows; respectively (16.0 vs. 7.9 ± 1.9 and 9.3 ± 3.3 seconds; *P* < 0.10). There was no significant association between lameness and any of the limb lesions studies (*P* > 0.05). Lame sows had wider joint angles for the knee, front and rear pasterns compared with non-lame sows (*P* < 0.05). Under the conditions of this study, lameness did not influence dynamic space requirements or the time taken for the different movement of the lying down-standing up sequence. However, lameness recorded was mild and thus, it might not be severe enough to affect the studied traits. However, results from this study could be important in the decision making process for housing specifications regarding sow gestation housing space needs for gestation sow housing in the USA.

Introduction

After reproductive problems, lameness is the second reason for sows being prematurely culled from commercial swine breeding herds. 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 lying-standing-lying postural sequence profile for sows. The sow has changed over the past 30-years through rapid genetic improvement for reproductive traits (Foxcroft, 2012) and these improvements may have affected the sows' utilization of her 3 dimensional space when making postural adjustments.

Previous work in the laying hen (Al-Rawi and Craig, 1975; Bogner et al., 1979; Dawkins and Hardie, 1989) has been paramount to help producers determine how much static and dynamic space a hen needs to perform behavioral and postural adjustments (i.e. crouch to stand, wing flap and perch). The European Union (E.U.) veterinary scientific committee reviewed several laying hen studies on static and dynamic space needs and the findings were included in the final report on the welfare of laying hens (1996). This report was foundational in the formulation the Directive 1999/74/EC which provides minimum standards (including space needs) for laying hens in the E.U.

In pigs, Baxter and Schwaller (1983) described and visually depicted the sow's lying down and rising up sequence when housed in farrowing stalls and the authors attempted to calculate the dynamic space required during such movements. However, the authors were unable to derive minimum space needs based on their observations, mostly due to the space variation used during the different movements within the rising up and lying-down sequence and suggested using sow body weights to calculate dynamic space needs. A similar approach was taken by Curtis and others (1989) where the lactating sows' body weight was used to calculate static and dynamic space requirements.

In addition, Baxter (1984) suggested that locomotion ability would cause few problems, if any, to the normal lying-standing-lying postural sequence, when sows have no space restriction. However, Anil and others (2009) reported that lameness could present challenges to the sows' ability to perform normal behaviors and this observations were supported through two studies that noted lame sows had a shorter latency to lie down than non-lame sows (Grégoire et al., 2013; Calderón Díaz et al., 2014).

Objectives:

1. Calculate the dynamic space requirement for lame and non-lame sows determined by their lying-standing postural sequence profile.

2. To characterize and pictorially depict the lying-standing postural sequence profile.

3. To identify other leg and toe and dew claw risk factors for non-lame and lame multiparous sows.

Materials & Methods:

Study location and housing

This study was approved by the Iowa State University Institutional Animal Care and Use Committee # 6-15-8035-S. The study was conducted at the Lauren Christian Swine Research Center experimental farm, Madrid, IA. Eighty-five multiparous sows (average parity 0.9 ± 1.14; range 0 to 4; average initial BW 136.1 ± 32.90 kg) were included. Sows were individually housed in gestation stalls (2.61 × 0.76 m) with fully slatted concrete flooring. All measures were recorded at approximately 30, 60 and 90 days of gestation.

Dynamic space requirements

Sows were moved from their home gestation stall to a gestation pen (2.17 × 2.42 m) where one camera (GoPro Hero, GoPro Inc., San Mateo, CA, USA) was positioned on the ceiling above the sow to continuously record the space needed to perform the lying down and standing sequences. Sows were video recorded between 8:00 AM and 5:00 PM. Video recording finished once the sow had either performed one lying down and one standing up sequence or if 2.5 hours of continuous video had been collected.

Lying down was defined as three sequence movements that have been previously described by Baxter and Schwaller (1983) where (i) the sow drops into a kneeling position, (ii) 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 (iii) finally, the sow lowers her hindquarters and finishes in either ventral or lateral recumbency. ***Standing up*** 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, (ii) then the sow starts to lift her hindquarters straight off the floor to achieve full standing position.

From the video, still frames for the different lying-down and standing-up sequences were extracted using AVcutty v3 (Andreas von Damaros, Krefeld, Germany, www.avcutty.de). Distortion from the still images was removed using GML Camera Calibration Software (V. Vezhnevets, A. Velizhev, N. Chetverikov, A. Yakubenko, GML C++ Camera Calibration Toolbox, 2011; Figure 1). Images were combined into a single image (Figure 2).

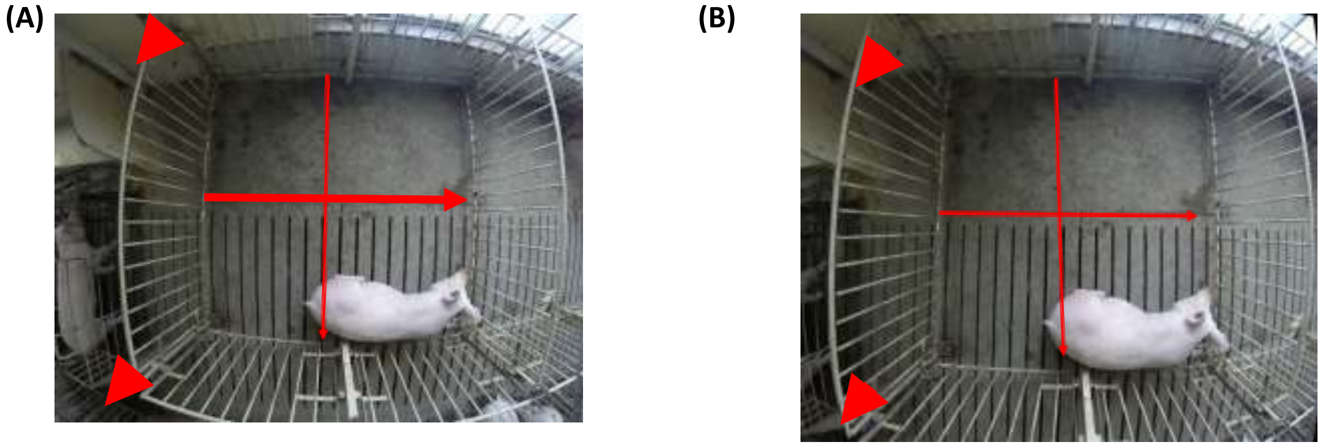


Figure 1. (**A**) Distorted image makes no correction for curvature of camera lens; (**B)** Raw images have been corrected for inaccuracies resulting from the curvature of the camera lens

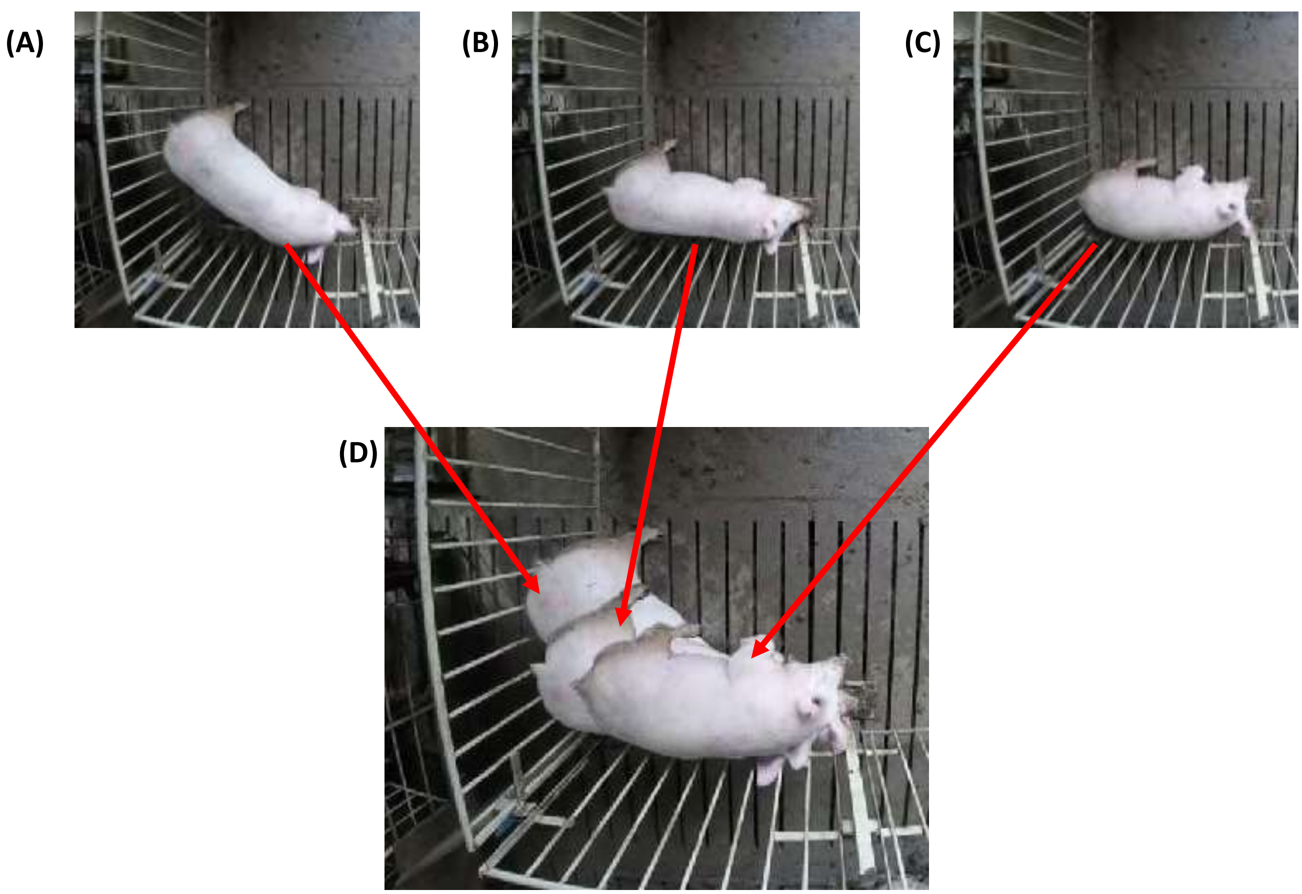


Figure 2. (A) he sow drops into a kneeling position, **(B)** then the sow rotates the upper part of her body to bring a shoulder and side of the head to rest on to the floor and **(C)** finally, the sow lowers her hindquarters and finishes in either ventral or lateral recumbency. (**D**) is the combination of figures 2A, 2B and 2C using Photoshop Elements 14.

Dynamic sow space requirements were measured in Adobe Photoshop Elements 14 by either counting the pixel number on the contour of the sows' body (Figure 3) or by utilizing an overlying grid to measure the sows' image (Figure 4).

Measuring method one: Counting the pixel number on the contour of the sows' body (Contour)

The contour of the sow was measured using the quick select pixel tool in Photoshop Elements 14 (Figure 3). The sow's outline drawn against the concrete was selected. The number of pixels was compared to the standard measurement of a clipboard measuring 0.072 m^2 (i.e. 1796 pixels), using the following equation:

$$\left(\frac{Sow\ pixels}{Clip\ board\ pixels}\right) * 0.072\ m^2$$

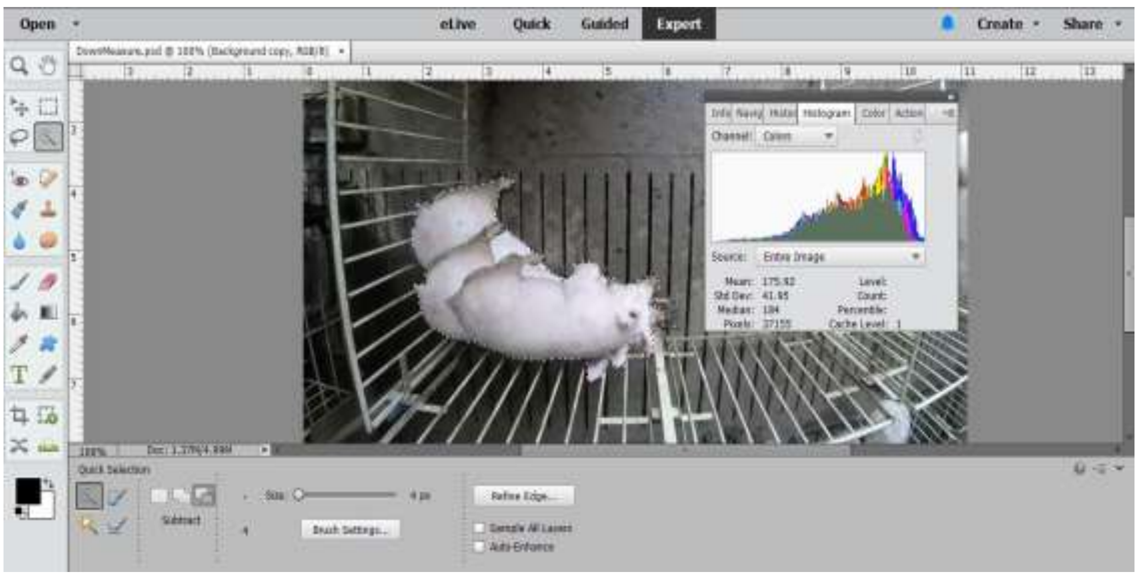


Figure 3. Drawing and measurement of the sow outline to calculate the dynamic space requirement to lie down and to stand up using Photoshop Elements 14.

Measuring method two: utilizing an overlying grid to measure the sows' image (Grid)

Space used to lie down and stand up was measured using the default square grid in Photoshop Elements 14 (Figure 4). The grid was overlaid on the sow image. Pixels in the grid square were measured and compared to the known clipboard pixel number to achieve an area/square using the following formula:

$$\left(\left(\frac{Squarepixels}{Clipboardpixels}\right) * 0.072m^2\right) * counted\ squares$$

Squares were manually counted and a square was included if it was at least half occupied by any part of the sow's body. Then the number of squares was multiplied by the square area to attain sow area.

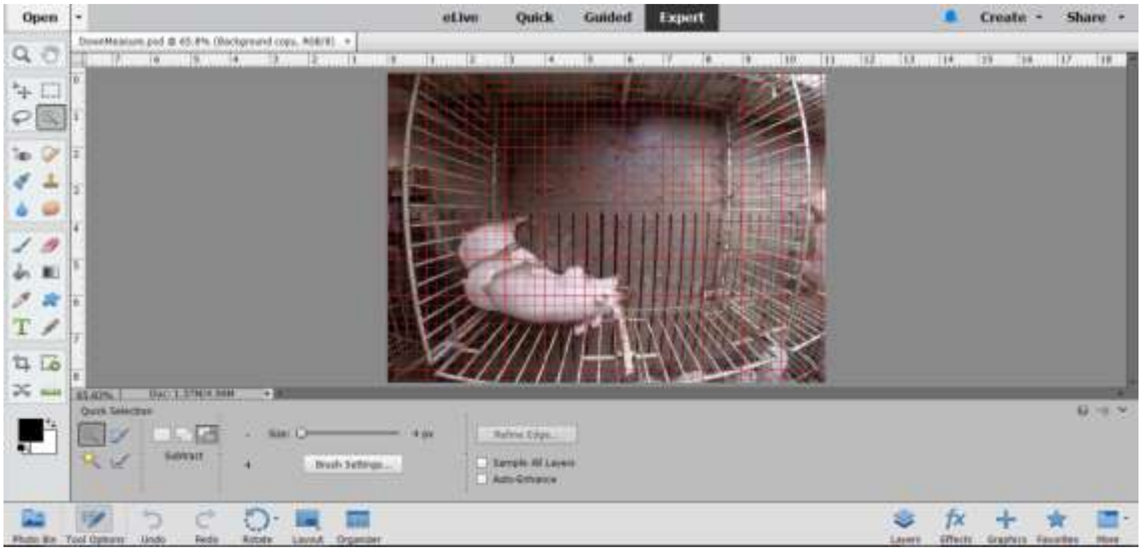


Figure 4. Overlaying a grid on the sow image to calculate the dynamic space requirements to lie down and to stand up using Photoshop Elements 14.

Behavior

Gestating sows' were individually recorded for one lying down and one standing up sequence when housed in a gestation stall. The sow profile was continually video recorded (GoPro Hero, GoPro Inc., San Mateo, CA, USA). The camera was positioned on the adjacent gestation stall, approximately 50 cm from the floor. Termination of the video recording occurred once the sow had performed one lying down and one standing up sequence or if 2.5 hours was reached.

Lying down was defined as three sequence movements that have been previously described by Baxter and Schwaller (1983; see Dynamic space requirements section). Sows were classified as ***having attempted to lie down*** if either of the first two movements were observed without the occurrence of the third movement in the sequence. However, in some cases, sows were observed to begin the third movement in the sequence, but being unable to successfully slide one of their rear legs under the body, they rapidly stood up again. In these cases, it was considered that lying had been attempted. ***Time*** from kneeling to shoulder rotation (KSR; seconds), time from shoulder rotation to lying (SRHQ; seconds), total time to lie down (TLIE; seconds), latency to lie down (LATENCY; minutes) and the number of attempts (ATTEMPTS) to successfully lie down and deviation occurrences were recorded.

Standing up was classified according to the sequence of movements described by Baxter (1984; see Dynamic space requirements section). A deviation was deemed to have occurred instead performing the fully standing sequence the sow lowered her hindquarters again and finished either sitting or lying on her sternum. ***Time*** (seconds) to stand up was defined as the first leg fold to sit (TLS), time from sit to rise (TSR), and total time to rise (TRISE) were recorded.

Lameness, feet and leg conformation and limb lesions

Lameness. Sows were visually scored for walking lameness on a 3-point scale adapted from the lameness scoring developed by Main et al. (2000; Table 1).

Table 1. Scoring system used to assess lameness in 85 multiparous sows on days 30, and 90 of gestation.

Score	Psychological and Behavioral Signs
1	Bright, alert and responsive Pigs stands squarely on all four legs Even strides
2	Bright but less responsive (may remain lying or dog sitting before eventually rising) Pig is limping Shortened stride
3	Unwilling to leave familiar environment Pig may not bear weight on affected limb Shortened stride

Feet and leg conformation. Feet and leg conformation was evaluated using picture frames obtained from the video. Two regions of interest (ROI) on the sow's body were used to assess feet and leg conformation. ROI 1 corresponded to the front legs and included the knee and front pastern joints. ROI 2 corresponded to the rear legs and included the hock and rear pastern joints. All digital images measurements were evaluated using the angle measurement tool in ImageJ (ImageJ, National Institute of Health, Bethesda, MD, USA) using a modified methodology by Stock and Colleagues (2015) from the scoring method developed by The Norwegian Pig Breeders' Association (Norsvin, Hamar, Norway).

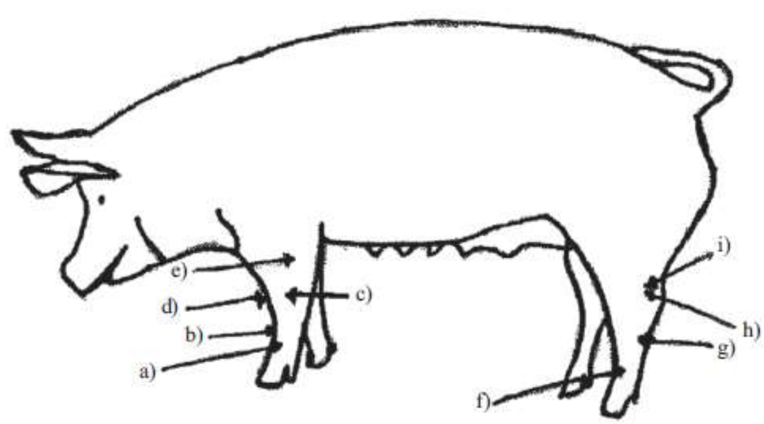
Knee angles were measured running on the front and back of the joint between the radius/ulna and carpals, with the contour sides of that joint acting as the anchor. Front pastern angles were measured in reference to the floor, where the contour of the joint between the carpals and metacarpals is the reference point for the front pastern measurement that runs a line down the top and bottom of the hoof to a straight edge that traces a line back. Hock angles were measured running on the front and back of the joint between the fibula/tibia and tarsals, with the contour sides of the joint acting as the anchor. Finally, rear pastern angles were measured in reference to the floor, where the contour of the joint between the tarsals and metatarsals is the reference point for the rear pastern measurement that runs a line down the top and bottom of the hoof to a straight edge that traces a line back.

Limb lesions. Limb lesions (environmentally induced defined as lesions from pressure or contact with fixtures and fittings) on the front fetlock, carpal joint, humerus, elbow, carpus, hock, tarsus-metatarsus joint, hind fetlock and metatarsus were scored according to their severity using the weighted scoring method of de Koning (1985) as modified by Calderón Díaz et al. (2013; Table 2).

Table 2. Limb lesions weighted scoring method of de Koning (1985) as modified by Calderón Díaz et al. (2014).

Categorization	Description	Score
Callus	Thickening of the epidermis and atrophy of glands	1
Swelling	Abnormal enlargement of a part of the body, typically as a result of an accumulation of fluid	2
Wound	Where the epidermis is interrupted but not ulcerated and there is no evidence of secondary infection	3
Bursitis	Acquired fluid-filled sac that develops in the subcutaneous connective tissue; usually occurs on the hind legs below the point of the hock or on the lateral sides of the elbow	3
Severe wound	Ulcerated lesions may or may not be accompanied by infection	4
Severe swelling	Characterized by redness and swelling accompanied by heat and pain	4
Severe wound + severe swelling		6

The sum of scores across all sites for each lesion type was calculated as the total score for each sow for each lesion type/inspection time. Figure 5 shows a topographical representation of the body location were limb lesions were scored.



Source: Calderón Díaz and Boyle, 2014.

Figure 5. Topographical representation of locations on right and left, front and rear limbs of sows inspected for limb lesions. a) Front fetlock; b) carpal joint; c) humerus; d) carpus; e) elbow; f) hind fetlock; g) metatarsus; h) tarsa-metatarsal joint; and, i) hock.

Statistical analysis

Each sow was considered the experimental unit. Only one sow was classified as severely lame during the duration of the trial; thus, lameness was re-classified as non-lame (score = 1) and lame (score = ≥ 2). Parity was reclassified as 0, 1 and 2+ due to the low number parity 2 sows and older. Severe wounds, severe swellings, and severe wounds plus severe swellings were not observed in any of the sows during the study. To study the association between lameness and limb lesions, medians were calculated for callus, swelling and bursitis and values were classified as ≤ median or > median lesion scores. All variables were analyzed in SAS v9.4 (SAS Inst. Inc., Cary, NC). For all the analyses, statistical differences were reported when $P < 0.05$ and statistical trends were reported when $P > 0.05$ and < 0.10.

Dynamic space requirements. Predicted variables 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. Models included gestation day, lameness score, area measuring method and parity as fixed effects. Univariate models were built to identify the association between callus, swellings, bursitis and area used. Statistical differences were reported when model source of variation was $P \leq 0.05$. When a main effect was a significant source of variation, levels from each main effect were separated using the PDIFF option. Results reported as least square means ± SEM.

Lie down and stand up sequences. Predicted variables were evaluated for normality using the Shapiro-Wilk test and examining the normal plot. All time variables were analyzed using mixed model equations methods in PROC MIXED. Models included lameness, gestation day and sow parity as fixed effects. Results are reported as least square means ± SE. The likelihood of kneeling, rotating shoulders, lying, folding legs, sitting, standing and deviations from the normal sequences were analyzed using binomial logistic regression in PROC GENMOD. Number of attempts to successfully lie down were classified as 1, 2 and 3+ and they were analyzed using multinomial logistic regression in SAS PROC GENMOD. For all logistic regression analysis, models included gestation day, lameness and parity as fixed effects. Results are reported as OR with the associated 95% CI.

Lameness. Logistic binomial regression analysis by use of the Wald statistic was used to investigate the association between lameness and the predictor variables. Data was analyzed in PROC GENMOD. Model included gestation day and sow parity as fixed effects. Univariate models were built to identify the association between callus, swellings, bursitis and lameness. Results are reported as odds ratios (OR) with the associated 95% confidence intervals (CI).

Feet and leg conformation. It has been observed that gilt feet and leg conformation deteriorates from the end of finisher period to the first parity (Fernàndez de Sevilla et al., 2009). Therefore, only data from gilts was used to investigate possible changes on feet and leg joint angles. Gilts represented the entire population of the 10th generation of divergently selected females for residual feed intake (RFI) at Iowa State University. Joint angles for knee, front and rear pastern, and hock were analyzed using mixed model equations methods in PROC MIXED. Models included gestation day, lameness score and RFI line as fixed effects. Sow was included as random effect. Univariable models were built to examine the possible association between joint angles and the presence of limb lesions. Results are reported as least square means ± SE.

VIII. Results:

Objective 1. Calculate the dynamic space requirements for lame and non-lame sows determined by their lying-standing postural sequence profile.

Twenty-eight sows were removed from the trial. Four sows were moved to the Vet Lab before completing their pregnancies because they were diagnosed as Severe Combined Immuno-Deficiency (SCID) carrier mothers. Twenty-four sows were determined to not be pregnant. Therefore, the final number of sows video recorded can be located in Table 3. Ninety-eight-percent of lameness was observed in the rear legs. It is important to note that only one sows was classified as severely lame (score 3).

Table 3. Number of observation for sows video recorded, number of lame sows and number of sows that successfully performed one lying-down-standing-up event at approximately 30, 60 and 90 days of gestation.

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

Results for the dynamic space requirements to lie-down and to stand-up are presented in Table 4. On average, sows used 1.2 ± 0.4 m^2 to lie down and to stand up. There were no observed differences in the dynamic space required to perform the lying-down or standing-up sequence between lame and non-lame sows ($P > 0.05$). There was no difference in the space required between the two measuring methods ($P > 0.05$). Space required to lie-down and stand-up increased as gestation progressed ($P < 0.05$) and as parity increased ($P < 0.05$).

Table 4. Dynamic space requirements for lame and non-lame multiparous sows at approximately 30, 60 and 90 days of gestation to lie down and stand.

	Laying down area, m^2		Standing up area, m^2	
Variables	**LS means**	**SEM**	**LS means**	**SEM**
Lameness				
Non-lame	1.17[a]	0.05	1.23[a]	0.05
Lame	1.16[a]	0.05	1.24[a]	0.05
Gestation day				
30d	1.09[b]	0.05	1.18[b]	0.05
60 d	1.17[a]	0.05	1.20[b]	0.05
90 d	1.22[a]	0.05	1.32[a]	0.05
Area measuring method				
Contour	1.19[a]	0.05	1.26[a]	0.05
Grid	1.14[a]	0.05	1.21[a]	0.05
Parity				
0	1.01[b]	0.05	1.08[b]	0.05
1	1.14[a,b]	0.08	1.31[a]	0.08
2+	1.34[a]	0.09	1.31[a]	0.09

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

Objective 2. To characterize and pictorially depict the lying-standing postural sequence profile.

Table 5 shows the time required to perform the different lying down movements. On average, sows took 13.9 seconds for KSR, 7.7 seconds for SRHQ, 20.5 seconds for TLIE and 66.1 minutes for LATENCY. Lameness was not a significant source of variation for any studied trait ($P > 0.05$). However, lame sows tended to take longer during KSR ($P = 0.08$), and spent less time standing ($P = 0.06$) compared with non-lame sows. Gestation day and parity were not associated with the time taken for the different movements in the lying down sequence ($P > 0.05$).

Table 5. Differences (LS means ± SE) between lame and non-lame multiparous sows in the time take taken to perform the different movements of the lying down sequence[1] at 30, 60 and 90 days of gestation.

	Time from Kneeling to shoulder rotation[1], sec		Time from shoulder rotation to lower hindquarter[1], sec		Total time to lie down[2], sec		Latency to lie down[3], min	
Variables	**LS means**	**SEM**	**LS means**	**SEM**	**LS means**	**SEM**	**LS means**	**SEM**
Lameness								
Non-lame	11.9[a]	1.61	7.6[a]	0.91	18.7[a]	1.51	69.7[a]	6.20
Lame	15.5[a]	1.56	8.0[a]	0.85	21.5[a]	1.44	54.1[a]	6.21
Gestation day[4]								
30 d	11.3[a]	1.57	8.1[a]	0.84	18.9[a]	1.51	66.1[a]	6.43
60 d	12.9[a]	1.69	7.2[a]	0.94	19.1[a]	1.65	64.7[a]	6.90
90 d	16.8[a]	2.12	8.1[a]	1.09	22.2[a]	2.09	54.9[a]	8.57
Parity								
0	15.6[a]	1.41	7.5[a]	0.82	21.7[a]	1.20	67.6[a]	5.05
1	12.7[a]	2.41	6.2[a]	1.43	17.1[a]	2.17	51.6[a]	8.88
2+	12.7[a]	2.35	9.6[a]	1.34	21.4[a]	2.07	66.5[a]	9.42

[1]Lying down was defined as three sequence movements that have been previously described by Baxter and Schwaller (1983) where (i) the sow drops into a kneeling position, (ii) 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 (iii) finally, the sow lowers her hindquarters and finishes in either ventral or lateral recumbency.

[2]Time to complete the lying down sequence from kneeling position to lowering the hindquarters and finishing in either ventral or lateral recumbency.

[3]Total time standing since observation starts until sow successfully lies down

[4]Observation were done at approximately 30, 60 and 90 days of gestation

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

There were no associations between gestation day, lameness status or parity and the likelihood of kneeling, shoulder rotation, lying down or ATTEMPTS (*P* > 0.05; Table 6). Additionally, there were no significant associations between gestation day, lameness status and the likelihood of performed a deviation from the normal lying down sequence (*P* > 0.05). However, sows parity 2+ were less likely to deviate from the normal lying down sequence compared with gilts (*P* = 0.07). The most common deviation observed was that the sow did not laid down in the allocated observation time (i.e. 2.5 hr), sows that did not rotated their shoulder and sows that finished the lying down sequence in a sitting position. Figure 6 pictorially depicts the different combinations of movements observed during the lying down sequence.

Table 7 shows the time required to perform the different standing up movements. On average sows took 8.0 sec for TLS, 6.9 sec for TSR, and 9.8 sec for TRISE. Lameness did not affect the time taken for TLS, TSR and TRISE (*P* > 0.05). Sows parity 2 had greater TLS compared with gilts and parity 2+ (*P* < 0.05). Additionally, parity 1 sows tended to take 8.1- and 6.7 sec more for TRISE than gilts and 2+ sows; respectively (*P* = 0.09). TLS was grater in at 60 d of gestation compared with 30 d and 90 d of gestation (*P* > 0.05).

There were no significant associations between gestation day, parity, lameness and the likelihood of performing different movement during the standing up behavioral sequence (*P* > 0.05). However, lame sows tended to be more likely to sit while transitioning from lying to standing compared with non-lame sows (*P* = 0.07; Table 8.). Figure 7 pictorially depicts the different combinations of movements observed during the standing up sequence.

Table 6. Likelihood (Odds ratios and 95% confidence interval) of performing the different movement of the lying down sequence[1], number of attempts and number of deviations in lame and non-lame multiparous sows at days 30, 60 and 90 of gestation

	Kneeling[1]			Shoulder rotation[1]			Lying down[1]			No. of attempts to lie down[2]			Deviations from the normal lying down sequence[3]		
		95% CI			95% CI			95% CI			95% CI			95% CI	
Variables	**OR**	**Lower**	**Upper**	**OR**	**Lower**	**Upper**	**OR**	**Lower**	**Upper**	**OR**	**Lower**	**Upper**	**OR**	**Lower**	**Upper**
Lameness ***(ref = non-lame)***															
Lame	0.81	0.36	1.81	1.42	0.76	2.67	1.06	0.59	1.91	1.06	0.59	1.91	0.70	0.31	1.59
Gestation day[4] ***(ref =30 d)***															
60 d	0.89	0.43	1.82	0.70	0.35	1.40	1.02	0.54	1.94	1.02	0.54	1.94	1.62	0.64	4.10
90 d	1.00	0.45	2.21	0.78	0.37	1.65	0.90	0.44	1.83	0.90	0.44	1.83	1.47	0.57	3.79
Parity ***(ref = gilts)***															
1	1.73	0.68	4.43	0.68	0.31	1.46	0.66	0.32	1.38	0.66	0.32	1.38	1.59	0.62	4.04
2+	1.26	0.64	2.45	1.90	0.79	4.60	0.94	0.42	2.09	0.94	0.42	2.09	0.25[a]	0.06	1.14

[1]Lying down was defined as three sequence movements that have been previously described by Baxter and Schwaller (1983) where (i) the sow drops into a kneeling position, (ii) 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 (iii) finally, the sow lowers her hindquarters and finishes in either ventral or lateral recumbency.

[2]Analysed using multinomial logistic regression

[3] Sows were classified as having attempted to lie down if either of the first two movements were observed without the occurrence of the third movement in the sequence. However, in some cases, sows were observed to begin the third movement in the sequence, but being unable to successfully slide one of their rear legs under the body, they rapidly stood up again. In these cases, it was considered that lying had been attempted.

[4]Observation were done at approximately 30, 60 and 90 days of gestation

[a] Indicates tendency compared with the reference category; $P < 0.10$

A


i) Kneeling
ii) Shoulder rotation
iii) Lower hindquarters and sow lands on floor

B


i) Bow
ii) Lower hindquarters and sow lands on floor

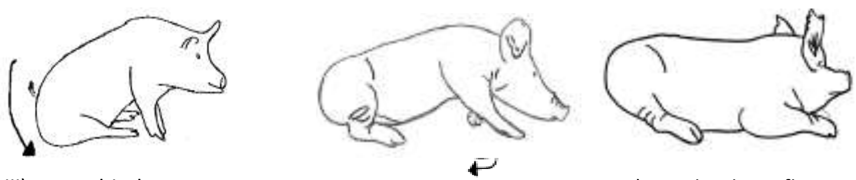
C


i) Kneeling
ii) Back legs slip
iii) Lower hindquarters and stretch front legs
iv) Sow lands on floor

D


iii) Lower hindquarters
ii) Bow
iii) Sow lands on floor

E


iii) Lower hindquarters
ii) Kneeling
iii) Sow lands on floor

F


i) Kneeling
ii) Lower hindquarters and sow lands on floor

G

i) Lower hindquarters ii) Sow lands on floor

H

i) Lower hindquarters

Figure 6. Different combinations of movements observed during the lying down sequence. A) Normal lying down sequence, B to H represent deviations from the normal lying down sequence.

Table 7. Differences (LS means ± SE) between lame and non-lame multiparous sows in the time take taken to perform the different movements of the standing up sequence[1] at days 30, 60 and 90 of gestation.

	Time from leg-fold to sit[1], sec		Time from sitting to rise up[1], sec		Total time to rise up[2], sec	
Variables	**LS means**	**SEM**	**LS means**	**SEM**	**LS means**	**SEM**
Lameness						
Non-lame	13.7[a]	3.06	4.8[a]	1.92	10.6[a]	2.31
Lame	6.9[a]	2.29	7.1[a]	1.54	11.5[a]	2.02
Gestation day[3]						
30d	8.5[b]	2.47	8.4[a]	1.66	12.2[a]	2.14
60 d	15.9[a]	2.77	4.6[a]	1.91	11.9[a]	2.39
90 d	6.5[b]	3.67	4.9[a]	2.44	9.1[a]	2.76
Parity						
0	4.6[b]	2.44	7.8[a]	1.47	7.9[a]	1.90
1	20.8[a]	3.59	2.8[a]	2.44	16.0[a]	3.13
2+	5.4[b]	3.66	7.3[a]	2.52	9.3[a]	3.27

[1]Standing up 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, (ii) then the sow starts to lift her hindquarters straight off the floor to achieve full standing position.

[2]Time to complete the standing up sequence from folding her legs beneath her body position to lifting hindquarters and achieving a full standing position

[3]Observation were done at approximately 30, 60 and 90 days of gestation

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

Table 8. Likelihood (Odds ratios and 95% confidence interval) of performing the different movements of the standing up sequence[1], number of attempts and number of deviations in lame and non-lame multiparous sows at days 30, 60 and 90 of gestation

	Leg folding[1]			Sitting[1]			Rising up[1]		
		95% CI			95% CI			95% CI	
Variables	**OR**	**Lower**	**Upper**	**OR**	**Lower**	**Upper**	**OR**	**Lower**	**Upper**
Lameness ***(ref = non-lame)***									
Lame	1.4	0.73	2.83	1.7[(a)]	0.93	3.35	1.5	0.65	3.34
Gestation day[2] **(*ref =30 d*)**									
60 d	1.1	0.53	2.29	0.9	0.49	1.99	0.9	0.41	2.17
90 d	1.1	0.50	2.42	0.8	0.41	1.87	1.1	0.45	2.95
Parity **(*ref = gilts*)**									
1	1.2	0.53	2.81	0.6	0.30	1.43	0.9	0.33	2.40
2+	1.4	0.60	3.70	1.2	0.50	2.76	1.0	0.36	2.94

[1]Standing up 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, (ii) then the sow starts to lift her hindquarters straight off the floor to achieve full standing position.

[2]Observation were done at approximately 30, 60 and 90 days of gestation

[(a)] Indicates tendency compared with the reference category; $P < 0.10$

A

i) Legs folded beneath her body

ii) Sow rises to a sitting position

iii) Lift hindquarters and sow achieves a full standing position

B

i) Sow ‘kneels’ and starts to lift hindquarters

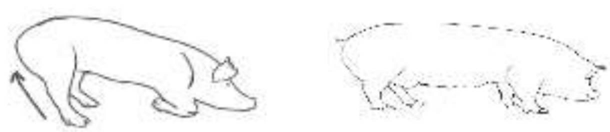
ii) Sow achieves a full standing position

C

i) Sow rises to a sitting position

ii) Lift hindquarters and sow achieves a full standing position

D



i) Lift hindquarters

ii) Sow achieves a full standing position

E

i) Legs folded beneath body

ii) Lift hindquarters and sow achieves a full standing position

Figure 7. Different combinations of movements observed during the standing up sequence. A) Normal standing up sequence, B to E represent deviations from the normal standing up sequence.

Objective 3. To identify other leg and toe and dew claw risk factors for non-lame and lame multiparous sows.

Gestation day and parity were sources of variation for the risk of lameness. There was an increased lameness risk on day 60 of gestation compared with day 30 of gestation ($P < 0.05$). Sows in their first parity were more likely to be lame when compared with gilts ($P < 0.05$; Table 9). There was no significant association between lameness and any of the limb lesions studied ($P > 0.05$).

Table 9. Association (Odds ratios and 95% confidence interval) between gestation day, sow parity and the risk of lameness in multiparous sows.

		95% CI	
Variables	**OR**	**Lower**	**Upper**
Gestation day[2]			
(Ref. = 30 d)			
60 d	2.9[a]	1.36	6.60
90 d	0.8	0.36	1.95
Parity			
(Ref. = gilts)			
1	3.7[a]	1.43	9.39
2+	1.0	0.44	2.55

[1]Sows were visually scored for walking lameness on a 3-point scale adapted from the lameness scoring developed by Main et al. (2000). Score 1 = Sow is bright, alert and responsive; she stands squarely on all four legs and has even strides; score 2 = sow is bright but less responsive (may remain lying or dog sitting before eventually rising), she is limping and she has shortened stride; score 3 = sow is unwilling to leave familiar environment, she may not bear weight on affected limb and she has shortened stride

[2]Observation were done at approximately 30, 60 and 90 days of gestation

[a] Significantly different from reference category; $P < 0.05$

Joint angles changes across gestation days were observed in the knee, front- and rear pasterns ($P < 0.05$; Table 10). Angles decreased 1.1 ± 0.45, 2.7 ± 0.86 and 3.1 ± 1.02 degrees in the knee, front and rear pastern, respectively from gestation days 60 to day 90 ($P < 0.05$) and a similar tendency was observed between gestation days 30 and day 90 ($P < 0.10$). Low RFI gilts had wider front and rear pastern joint angles ($P < 0.05$; Table 10). Lame gilts also had greater joint angles for the knee, front and rear pasterns compared with non-lame ($P < 0.05$). Hock joint angle was not associated with any of the predictor traits ($P > 0.05$). There was no association observed between joint angles and the presence of limb lesions in joints studied ($P > 0.05$)

Table 10. Differences (LS means ± SE) in front and rear pastern, knee and hock joint angles between lame and non-lame gilts from the 10th generation of females divergently selected for Residual Feed Intake (RFI) at days 30, 60 and 90 of gestation.

	Front Pastern[1]		Knee[2]		Hock[3]		Rear pastern[4]	
Variables	**LS means**	**SEM**	**LS means**	**SEM**	**LS means**	**SEM**	**LS means**	**SEM**
Lameness								
Sound	58.6[b]	0.70	160.2[b]	0.49	154.8[a]	0.45	61.1[b]	0.89
Lame	60.1[a]	0.88	160.5[a]	0.57	154.5[a]	0.55	63.7[a]	1.06
Gestation day[5]								
30 d	59.7[a,(b)]	0.89	160.5[a,(b)]	0.47	154.7[a]	0.55	62.7[a,(b)]	1.06
60 d	60.5[a]	0.87	160.8[a]	0.46	155.1[a]	0.54	63.8[a]	1.03
90 d	57.8[b]	0.85	159.7[b]	0.45	154.2[a]	0.53	60.7[b]	1.02
RFI line								
Low	60.9[a]	0.80	159.8[a]	0.41	155.2[a]	0.53	66.1[a]	1.05
High	57.8[b]	0.92	160.8[a]	0.47	154.1[a]	0.61	58.7[b]	1.22

[1]Front pastern angles were measured in reference to the floor, where the contour of the joint between the carpals and metacarpals is the reference point for the front pastern measurement that runs a line down the top and bottom of the hoof to a straight edge that traces a line back.
[2]Knee angles were measured running on the front and back of the joint between the radius/ulna and carpals, with the contour sides of that joint acting as the anchor.
[3]Hock angles were measured running on the front and back of the joint between the fibula/tibia and tarsals, with the contour sides of the joint acting as the anchor.
[4]Rear pastern angles were measured in reference to the floor, where the contour of the joint between the tarsals and metatarsals is the reference point for the rear pastern measurement that runs a line down the top and bottom of the hoof to a straight edge that traces a line back.
[5]Observation were done at approximately 30, 60 and 90 days of gestation
[a,b] Within each column, significant differences between levels of each predictor variable; $P < 0.05$
[(b)] Indicates tendency; $P < 0.10$

IX. Discussion:

Dynamic space requirements.

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 the use of the allometric equation $A = k * BW^{0.667}$ to derive minimum space requirements over a wide range of weights (Baxter, 1984; Hurnik and Lewis; 1991). However, other factors other than body size may affect the requirements for space allotments. Additionally, such approaches only measure static space requirements. Dynamic space requirements refer to the physical space occupied by an animal plus the extra space needed to perform non-locomotor movements such as eating, drinking, lying down and standing up (Curtis, 1989).

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 mostly due to the variation in space used during the different movements and suggested the use of body weights to calculate dynamic space. However, measurements were obtain using a very limited sample size (n = 5 sows) and all the animal used had very similar weight, and possible, body dimensions. A similar approach was taken by Curtis and others (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 requirements are greater than those observed in the present study. However, Curtis et al. (1989) based their calculation in the 95^{th} percentile static requirements. Furthermore, the length measurement used was recorded on day 21 post-farrowing while the width measurement was recorded between days 107 and 110 of gestation.

To our knowledge this is the first time gilt and sow dynamic space requirements have been calculated directly from the animal using digital images of the lying down-standing up process. We hypothesized that lame sows would need a greater dynamic space requirement because Bonde and Colleagues (2004) reported that severely lame sows displayed uncontrolled movements while lying down. However, under the conditions of this study, lameness did not affect the dynamic space needed to lie-down and stand-up. It is important to note, that lameness observed was mild and only one sow received a severe lameness score. Nonetheless, results from this study could be important when determining space needs for gestation sow housing in the USA. Although the majority of sows in the USA are housed in gestation stalls, it is likely that group sow housing will increase in use due to consumer concerns. Currently eight states (Florida, Arizona, Oregon, Colorado, California, Maine, Michigan and Ohio) have banned the gestation stall. Results from this 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 house in groups).

Lying-standing postural sequence profile.

To our knowledge, this is the first study to quantify time to perform each lying down and/or standing up movements. Other studies (Marchant and Broom, 1996; Bonde et al., 2004; Calderón Díaz et al., 2014a, Calderón Díaz and Boyle, 2014; Calderón Díaz et al., 2015a; Roca et al., 2016) have measured aspects of the lying down sequence such as the latency, time and number of attempts to successfully lie down.

Results for the time needed to lie down in this study are similar by those reported by Marchant and Broom (1996) and Calderón Díaz and others (2014) of approximately 20 seconds. Contrary to our hypothesis, lameness status was not associated with time to perform lying-standing movements. However, lame sows tended to take 2.6 seconds longer during KSR and to spend less time standing (i.e. 15.7 minutes) compared with non-lame sows. This supports the hypothesis that the lying-standing sequence would be most likely affected only when sows are severely lame.

Although no difference was observed between lame and non-lame sows in the different postures adopted during the lying down and standing up sequences, observations from this study expand our knowledge regarding sows' lying down and standing up. Calderón Díaz and Colleagues. (2015b) pictorially depicted the lying down sequence of 12 sows but due to the small sample size, variations to the normal sequence were not observed except in a severely lame sow. To our knowledge, this is the first time that a large number of different combinations of postures and movements adopted during the lying down and standing up sequences in sows have been illustrated.

Other risk factors for lameness in multiparous sows

Gilt selection using objective joint angle measurements is becoming increasingly important for gilt selection and sow longevity. It has been suggested that feet and leg conformation could change as sow ages. For example a study by Fernández de Sevilla and others (2009) reported that when visually scored, gilt feet and leg conformation deteriorated from the end of finisher period to the first parity. Thus, only first parity sows were used for this part of the project.

In this study, lame gilts also wider joint angles for the knee, front and rear pasterns; however, such differences were small and their biological relevance is unclear. It is possible that the variation in feet and leg joint angles between lame and non-lame sows is less marked that within sows. Mumm and others (2016a) measured hock angles between lame and non-lame sows using data collected only in the sound leg in the same population used for this study. The authors found no difference in hock angulation in different positions between lameness statuses. However, when hock angles in the lame and sound legs were compared, Mumm et al. (2016b) observed that lame legs had wider hock angles when compared with the sound leg (141.1 vs 136.9 ± 1.9 degrees, respectively) indicating an effort of the sow to balance her body while moving due to the discomfort she might be experiencing in the lame leg. Future research should follow first parity sows over several parities to identify if joint angle differences change over time and their possible effect on sow longevity.

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Project Publications (to date):

1. Mumm, J., Stock, J. D., Dekkers, J.C.M., Stalder, K. J., Calderón Díaz, J. A. Effect of lameness on hock angles of replacement gilts ASAS-ADSA 2016 Midwest Annual Meeting, Des Moines, IA, USA, March 14th - 16th, 2016. Journal of Animal Science. 94: supplement2: 8-8. doi:10.2527/msasas2016-017

2. Mumm, J., Stock, J. D., Dekkers, J.C.M., Stalder, K. J., Calderón Díaz, J. A. Identification of hock angle range in replacement gilts. ASAS-ADSA 2016 Midwest Annual Meeting, Des Moines, IA, USA, March 14th - 16th, 2016. Journal of Animal Science. 94: supplement 2: 37-37. doi:10.2527/msasas2016-079

3. Mumm, J., Stalder, K. J., Stock, J. D., Calderón Díaz, J. A. 2016. Identification of the Range of Hock Angles in lame and non-lame Replacement Gilts. Animal Industry Report AS 662, ASL R3115. Department Animal Science, Iowa State University, Ames, IA

4. Mumm, J.M., Stock, J.D., Azarpajouh, S., Stalder, K.J., Johnson, A.K., Calderón Díaz, J. A. Characterization of the lying down sequence in lame and non-lame sows. To be presented at the ASAS-ADSA 2017 Midwest Annual Meeting, Omaha, NE, USA, March 13th - 15th, 2017.

5. Mumm, J.M., Stock, J.D., Stalder, K.J., Johnson, A.K, Ramirez, A., Azarpajouh, S., Calderón Díaz, J. A. Dynamic space requirements of lame and non-lame sows determined by the lying-standing sequence. To be presented at the ASAS-ADSA 2017 Midwest Annual Meeting, Omaha, NE, USA, March 13th - 15th, 2017.

6. Mumm, J.M., Azarpajouh, S., Stock, J.D., Stalder, K.J., Johnson, A.K., Calderón Díaz, J. A. Do lame sows need more time to stand up? To be presented at the ASAS-ADSA 2017 Midwest Annual Meeting, Omaha, NE, USA, March 13th - 15th, 2017.

7. Stock, J.D., Mumm, J.M., Stalder, K.J., Dekkers, J.C.M., Johnson, A.K, Azarpajouh, S., Calderón Díaz, J. A. Changes in feet and leg angles in gilts divergently selected for residual feed intake during their first gestation. To be presented at the ASAS-ADSA 2017 Midwest Annual Meeting, Omaha, NE, USA, March 13th - 15th, 2017

8. Mumm, J., Stock, J., Azarpajouh, S., Johnson, A., Stalder, K.J., Ramírez, A., Calderón Díaz, J.A. Dynamic Space requirements of lame and non-lame sows as they lie and stand. To be published as part of the Department Animal Science, Iowa State University Animal Industry Report 2017. Department Animal Science, Iowa State University, Ames, IA.

9. Mumm, J., Stock, J., Azarpajouh, S., Johnson, A., Stalder, K.J., Calderón Díaz, J.A. Time taken for lame and non-lame sows to stand and lie. To be published as part of the Department Animal Science, Iowa State University Animal Industry Report 2017. Department Animal Science, Iowa State University, Ames, IA.

10. Mumm, J., Stock, J., Azarpajouh, S., Johnson, A., Stalder, K.J., Calderón Díaz, J.A. Depiction of lying down and standing up sequence in multiparous sows. To be published as part of the Department Animal Science, Iowa State University Animal Industry Report 2017. Department Animal Science, Iowa State University, Ames, IA.

11. Stock, J., Stalder, K.J., Mumm, J., Dekkers, J.C.M., Johnson, A., Azarpajouh, S., Calderón Díaz, J.A. Changes in feet and leg joint angles in gilts divergently selected for residual feed intake during their first gestation.. To be published as part of the Department Animal Science, Iowa State University Animal Industry Report 2017. Department Animal Science, Iowa State University, Ames, IA.