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Dynamic space utilization of lame and non-lame sows as determined by their lying-standing sequence profile

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TABLE OF CONTENTS

ABSTRACT

The primary objective of this project was to determine the dynamic space utilization for lame and non-lame sows during a lying-standing postural sequence. A secondary objective was to characterize the postures and movements for multiparous lame and sound sows and to identify differences in the lying and standing sequence. 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). Individual sows were moved to a pen on day 30, 60 and 90 of gestation and a ceiling mounted camera was installed above the pen to record a single lying-standing event. Observations ceased when the sow laid-down and stood-up or if 2.5 hours elapsed from recording commencement. Lying and standing sequence still frames were combined into a single image and measured in Adobe Photoshop Elements by counting the pixel number associated with contouring the sows' body or; counting squares on a grid that was overlaid on the sow's image. A second video of the sows' profile while standing in a gestation stall was collected on 30, 60 and 90 days of gestation. 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 (TLIE) were determined. In addition, latency to lie (LATENCY; minutes) and number of attempts (ATTEMPTS) to successfully lie were recorded. Time (seconds) to stand 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 sequence. 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+. On average, sows used 1.2 ± 0.4 m^2 to lie and to stand and there was no difference in the space required between the two measuring methods used ($P > 0.05$). Space required to lie and stand

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 spent less time standing (54.1 vs. 69.8 ± 6.20 minutes for lame and sound sows, respectively; $P = 0.06$) when compared to 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 the sow's attempts to lie. Sows in their first parity 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 limb lesions evaluated in the present study ($P > 0.05$). Under the conditions of this study, lameness did not influence dynamic space requirements or the time taken for the different lying-standing sequence movements. However, the observed lameness was mild and thus, it might not have been severe enough to affect the studied traits. The results from this study could be important when making breeding herd housing specifications decisions regarding sow gestation space needs in the U.S.

CHAPTER I: GENERAL INTRODUCTION

Introduction

After reproductive problems, lameness is the most important reason for premature sow culling from breeding herds (Stalder et al., 2004). Lameness is an economical (Dijkhuisen et al., 1989; Anil et al., 2009a; Rodriguez et al., 2011), worker morale (Bell and Main, 2011) and animal welfare issue (Dewey et al., 1993; Rowles, 2001; Anil et al., 2009b). Currently, there is very little information in the scientific literature about sow lameness etiology and severity on the lying-standing postural sequence profile. Moreover, there has been no postural profile pictorial depiction for 30 years. During this time, there has been rapid genetic improvement (Foxcroft, 2012) within the U.S. swine industry, which in turn may have affected the way pigs utilize it 3-dimensional (3D) space allocation when making postural adjustments. Previous laying hen work (Al-Rawi and Craig, 1975; Dawkins and Hardie, 1989) has been paramount to help producers determine the static and dynamic space needs to allow hens to perform a richer behavioral repertoire.

Baxter and Schwaller (1983) described and depicted the sows' lying and rising sequence when housed in stalls. They attempted to calculate the dynamic space required to perform the different movements, but were unsuccessful due to sample size and movement variation. The authors suggested that the sows' physical dimensions could be used to calculate static and dynamic space requirements, which was later confirmed in studies by Petherick (1983) and Curtis (1989).

Baxter (1984) further suggested that lameness would cause few, if any lying and standing problems if sows have no space restriction. Later studies disagreed with this statement, for example, Anil et al. (2009b), along with Grégoire et al. (2013), Calderón Díaz et al. (2014) and Roca et al., (2016) reported that lameness can present challenges to a sows' ability to perform normal lying and standing behaviors, noting that lame sows had a shorter latency to lie down when compared with non-lame sows.

Thesis Organization

This thesis contains five chapters. The first chapter is a general introduction which discusses the relationship between lameness and the lying and standing sequences in sows. The second chapter is a comprehensive literature review which examines the lying down and standing up sequences in pigs, lameness and dynamic spaces requirements in sows. The third and fourth chapters include modified versions of papers to be submitted to *Livestock Science* and *Applied Animal Behaviour Science* for consideration, respectively. Chapter 3 relates the dynamic space requirements in lame and non-lame gestating sows determined by their lying down and standing up sequences. Chapter 4 relates the lying and standing sequence differences for lame and non-lame gestating sows. A general conclusion follows in Chapter 5.

Outcomes

Conference abstracts

1. **Mumm, J. M.**, Stock, J. D., Azarpajouh, S., Stalder, K. J., Johnson, A. K., Calderón Díaz, J. A. 2017. Characterization of the lying down sequence in lame and non-lame sows. ASAS-ADSA 2017 Midwest Annual Meeting, Omaha, NE, USA, March 13th - 15th, 2017. Journal of Animal Science. 95 (supplement 1): 3.

2. **Mumm, J. M.,** Stock, J. D., Stalder, K. J., Johnson, A. K, Ramirez, A., Azarpajouh, S., Calderón Díaz, J. A. 2017. Dynamic space requirements of lame and non-lame sows determined by the lying-standing sequence. ASAS-ADSA 2017 Midwest Annual Meeting, Omaha, NE, USA, March 13th - 15th, 2017. Journal of Animal Science. 95(supplement 1): 6-7.
3. **Mumm, J. M**., Azarpajouh, S., Stock, J. D., Stalder, K. J., Johnson, A. K., Calderón Díaz, J. A. 2017. Do lame sows need more time to stand up? ASAS-ADSA 2017 Midwest Annual Meeting, Omaha, NE, USA, March 13th - 15th, 2017. Journal of Animal Science. 95(supplement 1): 3-4.

Technical publications

1. **Mumm, J. M.**, Stock, J., Azarpajouh, S., Johnson, A., Stalder, K. J., Ramírez, A., Calderón Díaz, J. A. 2017. Dynamic Space requirements of lame and non-lame sows as they lie and stand. Animal Industry Report AS 663, ASL R3198. Department Animal Science, Iowa State University, Ames, IA

2. **Mumm, J. M.**, 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. Animal Industry Report AS 663, ASL R3199. Department Animal Science, Iowa State University, Ames, IA

3. **Mumm, J. M.**, Stock, J., Azarpajouh, S., Johnson, A., Stalder, K. J., Calderón Díaz, J. A. Depiction of lying down and standing up sequence in multiparous sows. Animal Industry Report AS 663, ASL R3200. Department Animal Science, Iowa State University, Ames, IA

Expected Peer reviewed articles

1. **Mumm, J. M.,** Calderón Díaz, J. A., Stock, J. D., Azarpajouh, S., Johnson, A. K., Stalder, K.J. Characterization of the lying down sequence in lame and non-lame sows. *To be submitted for consideration to Applied Animal Behaviour Science*
2. **Mumm, J. M.,** Calderón Díaz, J. A., Stock, J. D., Johnson, A. K, Ramirez, A., Azarpajouh, S., Dekkers, J. C. M., Stalder, K.J. Dynamic space utilization of lame and non-lame sows determined by the lying-standing sequence. *To be submitted for consideration to Livestock Science*

Practical Implications

As consumers become more aware and reactive to the way in which animals are raised, several countries have developed housing and space specifications through legislation. For instance, the European Union established minimum space requirements for sows according to parity (i.e. gilts vs sows) and the number of animals per pen in the EU Council Directive 2008/120/EC. It is likely that other countries will follow similar trends. In the U. S. nine states have banned gestation stalls. In 2010, gestation stalls were banned in Tasmania and New Zealand, a voluntary ban was implemented in Australia, and it is expected that by 2017 gestation stalls will be completely phased out. In South Africa, gestation stalls will be banned by 2020. Therefore, it is imperative that we understand both static and dynamic space requirement estimates to enhance our ability to redesign housing features during all production phases for the sow. Furthermore, the knowledge of how space allowance and lameness interact can be used to improve swine welfare, and will in turn support the relationship between producers and consumers.

Author Contributions

Chapter 3: All authors were involved in the experimental design. J. M., J. S, S. A and J. A. C. D. collected data. J. M. and J. A. C. D. analyzed the data under the guidance of K. J. S. All authors contributed to drafting the manuscript.

Chapter 4: All authors were involved in the experimental design. J. M., J. S., S. A. and J. A. C. D. collected data. J. M. and J. A. C. D. analyzed the data under the guidance of K. J. S. All authors contributed to drafting the manuscript.

CHAPTER II. LITERATURE REVIEW

What is lameness

Lameness is defined by D'Allaire et al. (1987) under the context of locomotor problems, these included; unsoundness, abscess, injury, musculoskeletal disease, and 'downer sow' syndrome. 'Downer Sow' syndrome is later defined as "any condition causing a sow to be unable to stand or walk" (D'Allaire et al., 1987). As reviewed in a sow longevity study of 18 separate farms, removals for feet, leg and locomotion problems attributed 10.9% of total culls (Stalder et al., 2004). Stalder and others (2004) conclude that reproductive failure and feet and leg problems are the predominant reasons young sows (3 parities or less) are culled. Sow lameness is often a chronic problem (D'Eath, 2016). Boyle and co-workers (1998) noted that 32% of the females culled for lameness had produced only one litter. This is consistent with the findings reported by Pluym et al. (2011) where younger sows (parity 1 or 2) were at a greater risk of lameness compared to sows' parity 3 and higher. Locomotor issues continue to be a major problem in swine production with 10 to 20 % of removals due to lameness (Grégoire et al., 2013).These removals get included in the economic loss attributed to lameness that can be as high as $180/year based on factors such as lower productivity, lost piglets, increased pre-weaning mortality, high turnover costs, lower salvage value of sows, increased care costs, replacement lag, and lower output quality (Deen, 2010).

There are numerous ways that lameness is identified and measured. These scoring methods can be differentiated by subjective and objective categories. Subjective scores are deemed less reliable as they have more opportunity of bias or can be influenced by training. Most lameness scorings systems in the U.S. are subjective scoring systems used on farm (Roca et al., 2016). Different subjective scoring systems include scoring the conformation as the sow stands a locomotion score, or a combination of both (Enokida et al., 2010; Roca et al., 2016; Anil et al., 2009a; Sun et al., 2011; De Koning et al., 2012). Objective scoring systems are still in their infancy and difficult to use on a large scale at this point in time. However, they have been developed. In swine Sun et al., (2011) have developed a force plate system that objectively measures the weight distribution per leg of the animal as it stands. This technology has been reproduced and tested multiple times in recent years (Pluym et al., 2013; Paris-Garcia et al., 2015; Roca et al., 2016).

Etiologies of lameness

Infectious vs non-infectious: The causes of lameness can be divided into two categories infectious or non-infectious (Dewey et al., 1992), the infectious causes of lameness consist of infectious arthritis, Mycoplasma and Erysipelas. Rowles (2001) indicates Streptococcus suis, environmental Streptococcus spp that infects skin lesions, as well as Haemophilus parasuis, Mycoplasma hyorhinis and Erysipelothrix rhusiopathiae as associates to acute and/or chronic arthritis. The list of non-infectious causes is longer. According to Dewey et al. (1992) non-infectious causes of lameness include; osteochondrosis, foot rot, osteomalacia, fractures and other leg injuries. Anil et al. (2002) also discusses lameness as a result of injuries and lesions caused by the environment.

Injury is cause for alarm in any production scheme and is defined as physical tissue destruction to the detriment of its functioning (Webb and Nilsson, 1983). Anil et al. (2002) evaluated the relationship between stall size and sow injury. It was concluded that larger sows relative to stall size experienced more injury scores and lesions. These coming from both contact with the stall itself and overlapping into adjacent animals’ space with outstretched limbs that can be stepped on and injured (Anil et al., 2002). Pluym et al., (2011) indicates lameness and lesions are more prevalent in group housing systems.

It was found that 9.7 % of Belgium sows experienced lameness (Pluym et al., 2011). Rowels (2001) attributes 6 – 35 percent of sow culling to lameness. Lameness influences the behavior of the sows. Calderón Díaz et al., (2014) notes that lame sows have a tendancy to lie down quicker than sound sows. These results are also found in work by Gregoire et al., (2013) as well as Roca et al., (2016). Its important to note that these studies were done on sows during gestation. Enokida et al., (2010) investigated the risk of claw lesions, thus lameness, and its effects on the posture of the sows in lactation and found that claw lesions did affect the animals postural behavior. It has been hypothesized that lack of control in the final part of the lying sequence is due to lameness (Bonde et al., 2004).

Factors that can influence the prevalence on lameness on farms

Housing system and floowing type. Calderón Diaz and co-workers (2014), note that loose-housed sows have a significant increase for claw lesions when compared to sows housed in stalls. The claws and hooves are of great concern along with the floor as Webb and Nilsson (1983), describe that underworn hooves and overworn hooves can both be problematic for sows and producers (Webb and Nilsson, 1983). This was supported by Bonde et al. (2004) when they reported that flooring and other farm system and management factors cause most clinical and behavioral maladies. Most sows in U.S. production systems today are housed on concrete flooring. Previous indications that flooring affects lameness contrast studies where swine showed no significant lameness difference between production system types (Pluym et al., 2011).

Toe and Claw lesions and injury. Pluym (2011) noted that toe and claw lesion incidence increased with age, while lameness decreases. This points to the fact that lameness has multiple causes or etiologies. (Calderón Díaz and Boyle, 2014) found that limb lesions and difficulty adapting to confinement have a greater influence on sow welfare and behavior when stalled as opposed to the flooring on which the sows were housed. Toe and/or claw lesions may serve as infection entry sites that could affect joints and cause abscesses in other tissues (Pluym et al., 2011). It is important to point out that non-injurious tissue erosion can occur and is seen in hoof and toe wear (Webb and Nilsson, 1983).

Relationship with lying and standing

Bonde et al. (2004) reported an association between lameness and uncontrolled lying behavior in lactating sows. Baxter (1984) suggested that locomotor ability or lameness would cause few problems, if any, to the normal lying-standing sequence, when sows have no space restriction. However, Anil et al., (2009a) reported that lameness could present challenges to the sows' ability to perform normal behaviors and these observations were supported by two studies that noted lame sows had a shorter latency to lie down when compared to non-lame sows (Grégoire et al., 2013; Calderón Díaz et al., 2014).

Baxter and Schwaller (1983) described and visually depicted the sow's lying and rising sequence when housed in farrowing stalls, they also tried to calculate dynamic space required for these movements. Baxter (1984) described the lying process for the sow as; lowering herself to her knees, sliding one knee under her body so that she rests on one knee and a shoulder, then gently drops her hind quarters to the ground finishing the process in sternal or lateral recumbency; and the standing process as; the sow will rapidly twist the center of gravity over her legs onto her sternum, from there the sow will rise into the sitting position, after pausing she will lunge forward in a jerking motion of the head and neck to counterbalance the weight of her hindquarters, the motion may include taking one or two steps to adjust balance (Baxter, 1984; Baxter and Schwaller, 1983). However, the authors were unable to derive minimum space needs from their observations, due in large part to the space variation used during the different movements within the lying and rising sequence. The lying and standing sequence depicted and described by Baxter (1983) is seen as the typical lying and standing motion of domestic sows; however, the author noted that individual animals may develop methods that are not included in the description. Baxter (1983) also acknowledged that there may be environmental constraints that require the sow to make changes to the typical sequence of lying or rising.

Animal welfare:

The five freedoms are well known internationally (Mellor, 2016). One can hypothesize, that lameness can negatively affect four of the five freedoms on farm. For example, a lame animal is less likely to stand and eat, which could result in hunger, thirst and malnutrition (Anil et al. 2009b). Parsons et al. (2015) found that lying increased, frequency of sows at the drinker decreased and frequency of sows in their home pen increased in sows where lameness was induced. Although (Parsons et al., 2015) showed no differences in eating activity due to lameness, other studies indicate that lameness and discomfort or illness manifest as a decline in feed intake (Weary et al., 2009). Enokida et al. (2010) notes that sows in the highest category for claw lesions spent more time lying down than sows with fewer lesions. They further interpret that “claw lesions and postural behavior may raise some concern about animal well-being on commercial farms” (Enokida et al., 2010) Posture duration (lying or standing), is related to animal comfort (Anil et. al, 2002). It has been suggested that, based on the time taken for sows to lie down and rise, that the space available for them to do so leaves the animals in an uncomfortable state (Anil et al., 2002). This space restriction becomes more problematic as sows increase in size, as well as pregnancy advancement (Anil et. al, 2002). This violates the second freedom, “freedom from discomfort”. Tapper et al., (2013), Roca et al., (2016) and Paris-Garcia et al., (2015), using a chemically induced model of lameness have clearly demonstrated that sows display pain when using mechanical nociception threshold tests. Other studies (Anil et al., 2002; Anil et al., 2009b) whom have used sows with varying degrees of naturally occurring lameness also support that the pain thresholds and behavior differences due to lameness are similar between natural and simulated lameness conditions. In addition, pain folds into the third freedom “freedom from pain, injury and disease”. As noted previously, multiple diseases can cause lameness, multiple studies have demonstrated pain, and studies have indicated that bursitis, calluses, claw lesions and injuries can be a resultant of lameness (Calderon Diaz et al., 2014; Anil et al., 2007). Finally, sows when lame, show alterations in their gait, stride length and mobility, (Roca et al., 2016; Rowles, 2001; Bell and Main, 2011) which conflicts with “freedom to express normal behavior.”

Animal welfare acknowledges a continuum for an animal’s state of being, from very well to very ill (Curtis and Johnson, 2005). Welfare ranges from ‘very poor’ to ‘very good’, is a measurable trait, and points to suffering as an indicator, while keeping in mind that it may occur even when being hidden by anesthesia, analgesics, or immune system problems which are difficult to see (Phillips and Piggins, 1992). The premise of this statement allows for a sliding scale so traits can be assessed, while keeping in mind many other factors. This can be analyzed from two very different perspectives. According to (Lassen et al., 2006), people familiar with modern production practices will likely estimate the overall animal welfare based on the average, where individuals from differing backgrounds may find it more important to estimate animal welfare from the perspective from the individual animal that is in the worst condition.

Space

Baxter (1983) noted as far back as the 1980's a concern over welfare issues when sows were housed in close confinement. McGlone et al. (2004) defined space in three ways (a) static space "the space required to physically accommodate or contain the body", (b) social space "the space animals need to socially interact without obstruction" and (c) dynamic space "the space needed to make normal postural adjustments without being obstructed by pen materials"(McGlone et al., 2004). Petherick (2007) and Petherick and Phillips (2009), noted that animals need extra space to move between standing and lying and vice-versa.

Collection of the sow space measurements varies in terms of technique. Baxter and Schwaller (1983) utilized a system of mirrors to measure sow movements on the opposite side of the sow when lying and rising. An Italian study of crossbred pigs utilized digital images and pixel number to calculate the area occupied by pigs ranging in weight from 47 to 198 kg (Pastorelli et al., 2006).

It was suggested by Baxter and Schwaller (1983) to use sow body weights to calculate dynamic space needs. Curtis et al., (1989) took a similar approach where the lactating sows' body weight was used to calculate static and dynamic space requirements. The space relationships between pen mates and neighboring animals should also be considered when evaluating lying and standing postures. The K value is a method of converting body weight of animals into a 2-dimensional value for floor space (Gonyou, 2006). When using previous studies (Petherick, 1983; Gonyou, 2006), investigating allometric equations, Petherick and Phillips (2009) indicated that the space that an individual (regardless of species) requires to stand and lie can be accurately estimated by $A= 0.047W^{0.66}$. Where A is area in m^2, and W is live weight in kg (Petherick and Phillips, 2009). Physical points for: length, breadth and height have been used to create an allometric equation that accurately estimated the 3-dimensional space necessary for animals from the same species at different weights (Baxter and Schwaller, 1983). This process is now known as allometry and is revisited and explored by Petherick (2007), and Petherick and Phillips (2009). The static space of an animal can be measured by simply measuring the body weight, length from snout to back of the ham, height to the highest point of the back, and breadth across the widest points of the shoulder, back and ham (Curtis et al., 1989; McGlone et al., 2004). Although, this equation only accounts for the static space requirements. However, information points to the fact that space allocation affects pig performance when it falls below some minimal level (Petherick, 1983). It has been previously reported that the minimum space requirement of pigs on fully slatted floors is $0.027W^{0.67}$ (Phillips and Piggins, 1992). The earlier work by Petherick (1983), Phillips and Piggins (1992), and Baxter (1983) may have greater value for defining the static space requirement for sows, and does not very well encompass the dynamic space that a sow uses in confinement. Sow length, sow breadth (width at the widest part of the body most commonly the shoulder), and sow height are the three main dimensions taken into account for spatial allowance (McGlone et al., 2004; Baxter, 1983). Designing facilities with solid pens that have been constructed to a uniform area based on manufacturing and assembly ease does not most accurately account for biological differences in each sow given age and maturity.

The housing system type affects the amount of space provided for each sow. Group housing of animals is a complex problem that is more recently coming to the industry forefront

(Petherick, 2007). Space per animal for large groups is not as simple as multiplying the requirement by number of animals, as group space can be shared (Petherick, 2007). In large groups, the question of how much space must be provided hinges on synchronicity of behavior, meaning do all the animals perform the same behavior at the same time (Petherick, 2007). In livestock, there is very little information on how animals time-share space (Petherick, 2007). Shared space was discussed by Petherick (1983) and further explored by Petherick and Phillips (2009). These authors acknowledged that at certain K values, animals in transport may be able to lay down using shared space but struggle to rise. The motivations for animals to perform certain behaviors, whether they perform those behaviors simultaneously or not, and how much space is required to perform the behaviors are valuable items to explore with future research especially in swine. Curtis et al., (1989) defines the necessary movements of a sow as eat, drink, defecate, urinate, lie down and stand up.

Regarding space, Petherick (2007) establishes that one should keep in mind the purpose, duration, amount, and quality for the space provided to the animal. In defining the ‘quality’ of space, it should reflect the function or purpose of the space (Petherick, 2007). The overarching theme for any system is that the animal needs must be met and accounted for, while still meeting acceptable performance standards (Stalder et al., 2007).

Legislation regarding space allowance for gilts and sows

In livestock production, space allowance influences animal welfare and farm profitability (Petherick, 2007; Barnett et al., 2001). In 2008, the European Union published Council Directive 2008/120/EC, this outlined legislation that removed gestation stalls from swine production in member states.

Beginning in 2013, the European Union did not allow gestation stalls use as long term housing for swine (Council of the European Union, 2008). This same directive outlines the minimum space that gilts and sows must have available as 1.64 m^2, and 2.25 m^2, respectively. This spatial requirement dictates the space needed for each animal in regards to a group housing system.

The requirements set forth by the European Union, are based on sparse data. We know from Foxcroft (2012) that the genetics of production swine have changed, meaning that physical dimensions of the sows may have also changed since previous space and lying-rising studies. Technologies have also changed since the 1980's when Baxter and Schwaller first depicted the lying and rising sequences (Baxter, 1983). The scope with which the public views animal welfare and swine production has also changed. These changes garner the need for current research into the space utilization and lying-standing behavioral processes performed by the modern production sow.

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CHAPTER III. DYNAMIC SPACE UTILIZATION FOR LAME AND NON-LAME GESTATING SOWS DETERMINED BY THE LYING-STANDING SEQUENCE

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ABSTRACT

The objective of this study was to calculate the dynamic space utilization of lame and non-lame sows determined by their lying-standing postural sequence profile. Eighty-five multiparous 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 of lying and standing sequences 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 filled halfway 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, parity, 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 ± 0.4 m^2 to lie and to stand. There was no difference between the CONTOUR and HALF-GRID methods ($P > 0.05$), using the FULL-GRID sows required 0.3 m^2 more 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 ± 0.12 m^2 for D-PIVOT and 7.2 ± 0.15 m^2 for R-PIVOT to turn around. Space utilized to lie-down and stand-up increased as gestation progressed ($P < 0.05$). Space utilized to lie, stand and turn around was higher for older parity sows

(P < 0.05). Under the conditions of this study, lameness did not influence dynamic space utilization; however, lameness recorded was mild and might not have been severe enough to affect the results. These results could be important in decision-making process for housing specifications regarding US sow gestation housing.

Keywords: Dynamic space utilization, Lameness, Lying, Rising, Sows

Highlights

- Dynamic space utilization was estimated for lame and non-lame sows
- Lying-standing sequence was used to estimate dynamic space utilization
- On average, sows needed 1.2 ± 0.4 m^2 to lie-down and to stand-up
- Lameness did not affect the space used to lie-down, stand–up or to turn around.
- Dynamic space utilization differed between measurement method used for estimation

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 size may affect the requirements for 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 and colleagues (2008) have noted genetic differences in 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. Eighty-five sows (average parity 0.9 ± 1.14; range 0 to 4) were included in this study. Gilts used represented the entire population from the 10^{th} generation of Yorkshire pigs divergently selected for RFI (n = 26 LRFI and n = 20 HRFI) at Iowa State University (Cai et al., 2008). The remaining 39 multiparous sows were cross-bred Large White × Landrace. Hereafter, all animals will be referred to as sows.

Sows were individually housed in gestation stalls (2.61 × 0.76 m) with fully slatted concrete flooring. The gestation barn was double curtain sided to allow for natural ventilation. Additional fans provided 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 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 × 2.43 m L and 2.17 m W × 2.43 m L) available at the farm for video recording. The flooring type 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, sows were visually scored for walking lameness using a 3-point scale adapted from the lameness scoring developed by Main and others (2000) where 1 = sow is bright, alert and responsive, sow stands squarely on all four legs and has even strides; 2 = sow is bright but less responsive (may remain lying or dog sitting before eventually rising), she is limping and has shortened stride; and 3 = sow is unwilling to leave 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. 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."

Videos were split into single frames using AVCutty software, (AVCutty v3.5, Andreas von Damaros, Krefeld, Germany, www.avcutty.de). Two to five still images for each sow performing the lying and standing sequence were selected by a trained observer. 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 pen bars and floor slats to ensure proper placement (Figure 2).

2.2.3. Dynamic Space Utilization

Dynamic space utilized to lie and stand as well as space used to turn around were calculated. 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 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 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) sow 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 lameness score 3 during the entire 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. 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 of (SAS v9.4, SAS Inst. Inc., Cary, NC). Models included lameness score, area measuring method, gestation day, and parity as fixed effects. Sow was included as a random effect.

As genetic line was confounded by parity, 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. Results are reported as least square means ± SEM.

3. Results

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. Twenty-four sows were not pregnant (Table 1). Ninety-eight-percent of lameness was observed in the rear legs. Only one sow (P 0, HRFI line) was classified as lameness score 3 and was removed from the analysis.

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

On average, sows used 1.2 ± 0.4 m^2 to lie and to stand. There were no observed differences in the dynamic space used to perform the lying or standing sequence between lame and non-lame sows ($P > 0.05$). Method used to calculate space utilization was a significant source of variation. While there was no difference between the CONTOUR and HALF-GRID methods ($P > 0.05$), when using the FULL-GRID sows utilized 0.3 m^2 more to lie and to stand compared with the other two measuring methods ($P < 0.05$; Table 2). Space used to lie and stand increased as gestation progressed to 90 days ($P < 0.05$) and as parity increased ($P < 0.05$; Table 2). When comparing dynamic space utilization between RFI lines, LRFI sows used 0.2 m^2 more to stand compared with

HRFI sows (1.25 vs 1.06 ± 0.05 m^2; $P < 0.05$). There was no observed difference between genetic lines (HRFI or LRFI) for the dynamic space used while lying (1.12 vs 1.03 ± 0.05 m^2; $P > 0.05$).

3.2. Space Utilized to Turn Around

There were no observed differences in the dynamic space used to turn around between lame and non-lame sows ($P > 0.05$) or between gestation days ($P > 0.05$). Method used to calculate space utilized while turning around was a significant source of variation with more space needed when using the R-Pivot method ($P < 0.05$; Table 2). Space to turn around was greater for 2+ parity sows compared to gilts (Parity 0; $P < 0.05$). Further, there was no difference between RFI lines in the space used to turn around (4.1 ± 0.17 for the low RFI line and 4.0 ± 0.21 m^2 for the 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 time gilt and sow dynamic space utilization has been calculated directly from digital images of the lying-standing process. Previous studies derived dynamic space needs using the *k*-value equation (i.e. $A = 0.047BW^{0.66}$) that was developed by Petherick (1983) using the sow body weight 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, and possibly, body dimensions. 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 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 and others (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 and colleagues (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 because Bonde and colleagues (2004) reported that severely lame sows displayed uncontrolled movements when lying in the farrowing stall and Calderón Díaz and others, (2014a, 2014b) reported that severely lame lactating sows had a shorter latency to lie down. Similarly, Grégoire and others, (2013) noted that lameness has potential to affect the transition from lying to standing in both open 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 was mild and only one sow received a lameness score 3. Even so, these authors believe that these results are an accurate representation of the lameness seen in industry; as severely lame sows are easily recognized and dealt with according to farm protocol, and thus would not be available for study in whole farm samples. Furthermore, differences between studies could be due to sows being in different stages of production (e.g. lactating sows were used in previous studies whereas gestating sows were observed for the present study), 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 the possible lameness effects for a sow to control movements while lying and standing and the space needed to perform such 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 confines of static space requirements for sows 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). The overestimation when using the FULL-GRID method stems from the sows' extremities such as the tail and ears which extended to multiple grid squares beyond the bulk of the sow's body. When measuring for lesion scores, previous work by Anil and others (2002) suggests that high tail maneuverability allows for avoidance of contact with the 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 body bulk.

Previous space results report increased space as parity progressed. 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 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 (Bøe et al., 2011; McFarlane et al., 1988). Bøe and colleagues (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 which averaged 1.57 m. According to Anil and others (2002), average gestation stall dimensions are 1.82 m L × 0.59 m W. This calculates to 1.06 m^2 for total sow area in a gestation stall. 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) found 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 concludes 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. Regardless of calculations, the space a sow requires to turn around impacts stocking density and current production systems greatly. Harris et al., (2006) note that gilts in groups 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 more than 25 kg prefer to lay in contact with conspecifics 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 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 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, lameness recorded was mild and thus, it might not have been severe enough to affect the studied traits. Current technology offers accurate and efficient ways to measure dynamic space requirements for sows and it could be used as an effective tool for housing design or retrofitting facilities. Results from this study could be important as a benchmark for minimum dynamic space requirements when determining space needs for gestation sow housing in the USA.

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Table 1. 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. 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, m^2		Standing up area, m^2		Turn around area, m^2	
	LS Means	SEM	LS Means	SEM	LS Means	SEM
Lameness						
Non-lame	1.21^{a}	±0.05	1.27^{a}	±0.05	4.51^{a}	±0.13
Lame	1.21^{a}	±0.05	1.30^{a}	±0.05	4.56^{a}	±0.14
Gestation Day						
30d	1.17^{a}	±0.04	1.25^{a}	±0.05	4.56^{a}	±0.14
60d	1.19^{a,b}	±0.05	1.23^{a}	±0.05	4.38^{a}	±0.16
90d	1.26^{b}	±0.05	1.37^{b}	±0.05	4.67^{a}	±0.18
Measuring method						
CONTOUR[1]	1.13^{a}	±0.04	1.19^{a}	±0.05	-	-
FULL-GRID[2]	1.41^{b}	±0.05	1.51^{b}	±0.05	-	-
HALF-GRID[3]	1.10^{a}	±0.05	1.15^{a}	±0.05	-	-
D-PIVOT[4]	-	-	-	-	1.90^{a}	±0.12
R-PIVOT[5]	-	-	-	-	7.17^{b}	±0.15

Table 2 continued

Parity						
0	1.13[a]	±0.04	1.26[a]	±0.05	4.15[a]	±0.13
1	1.14[a]	±0.06	1.28[a]	±0.06	4.54[a,b]	±0.2
2+	1.35[b]	±0.07	1.32[a]	±0.07	4.92[b]	±0.21

[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; $P < 0.05$.

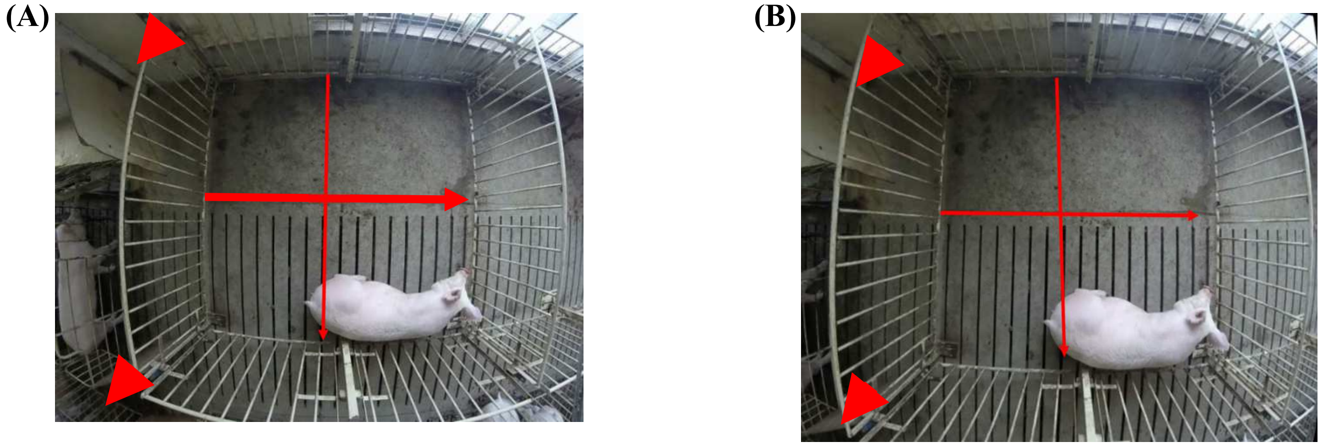

Figure 1. Top view images of sows' video recorded for one lying-down-standing-up event at approximately 30, 60 and 90 days of gestation in a study estimating dynamic space utilization to lie-down, stand-up and turn around in lame and non-lame multiparous commercial sows. (**A**) Distorted image makes no correction for curvature of camera lens; (**B**) Raw images have been corrected for inaccuracies resulting from the curvature of the camera lens.

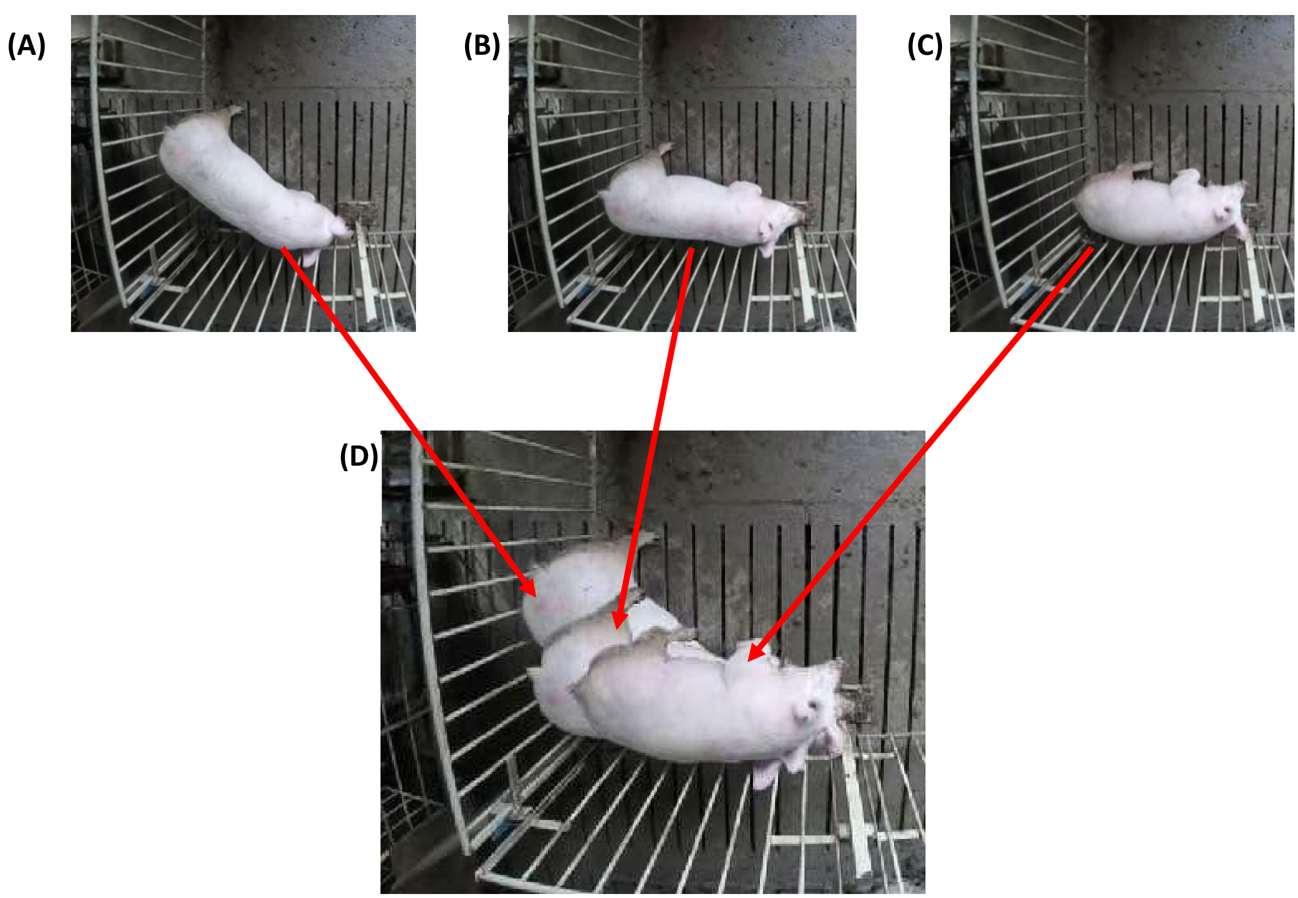

Figure 2. Layering of images according to the lying down sequence of multiparous sows video recorded for one lying-down-standing-up event at approximately 30, 60 and 90 days of gestation in a study estimating dynamic space utilization to lie-down, stand-up and turn around in lame and non-lame multiparous 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.

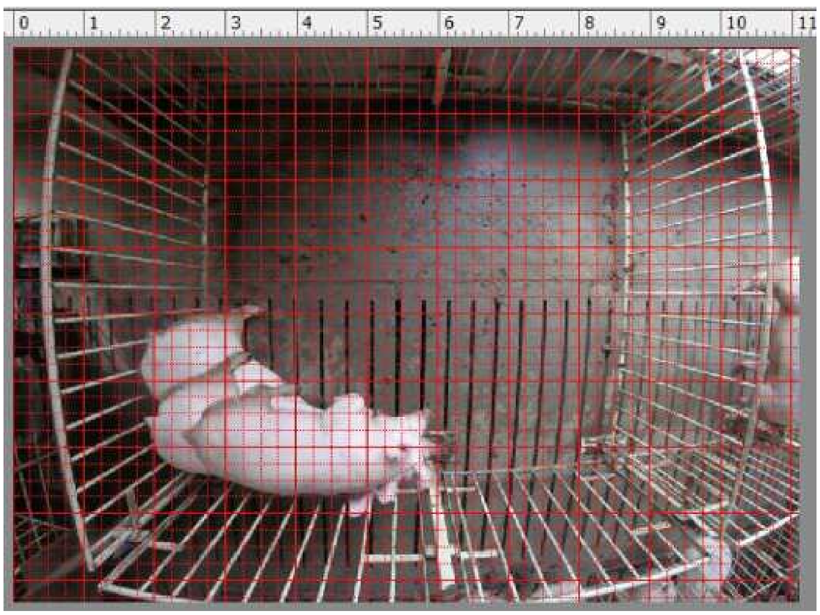

Figure 3. Overlaying a grid on the sow image to calculate the dynamic space utilization to lie down and to stand up at approximately 30, 60 and 90 days of gestation in lame and non-lame multiparous commercial sows. Two methods were used using the default grid view in Photoshop Elements 14. First, grid squares that where at least half of the area (HALF-GRID) was taken up by the sow were manually counted. In a similar way, the grid squares were counted if any part of the sow body was seen in them (FULL-GRID).

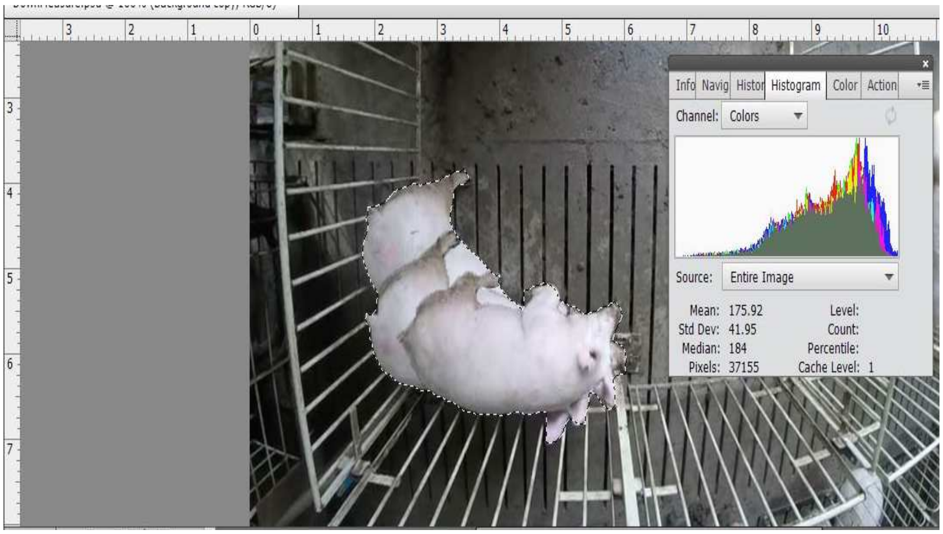

Figure 4. Drawing and measurement of the sow outline (CONTOUR method) to calculate the dynamic space utilization to lie down and to stand up at approximately 30, 60, and 90 days of gestation for lame and non-lame multiparous commercial sows using Photoshop Elements 14.

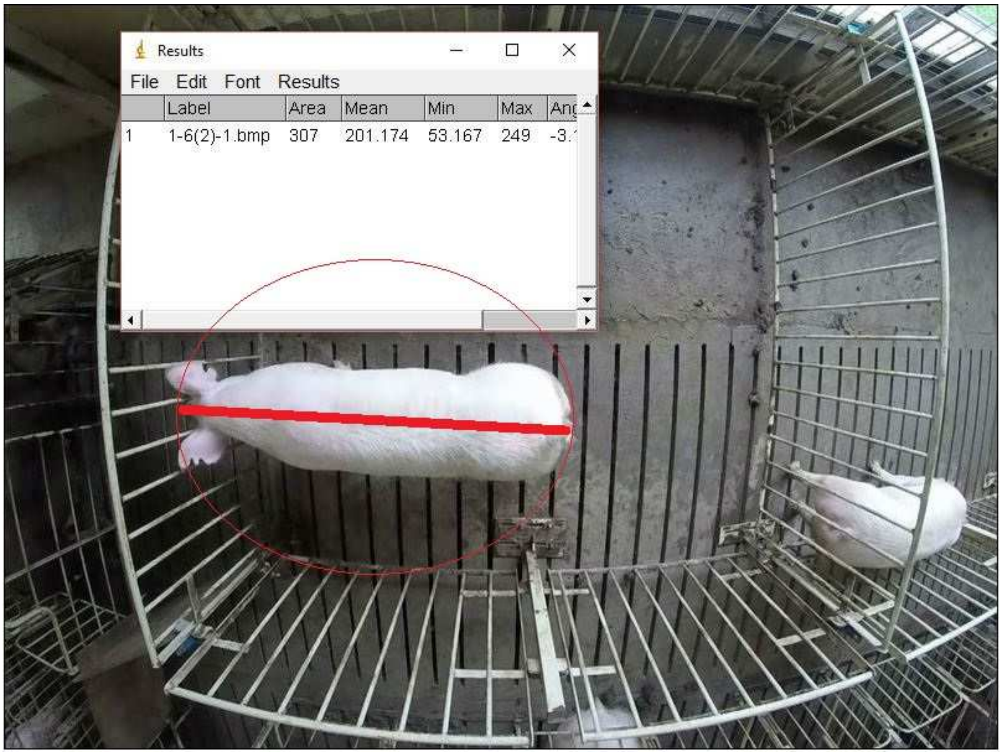

Figure 5. Measurements of the dynamic space utilized to turn around in lame and non-lame multiparous commercial sows at approximately 30, 60 and 90 days of gestation. First, an image of each sow while standing straight was taken. Using ImageJ software (ImageJ, National Institute of Health, Behesda, MD, 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.

CHAPTER IV. CHARACTERIZATION OF THE LYING AND RISING SEQUENCE IN LAME AND NON-LAME SOWS

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Abstract:

The objectives of this study were to characterize the postures and movements for the lying and standing sequence in multiparous sows and identify differences between lame and sound sows, while documenting the lying and standing processes. A total of 85 sows (average parity 0.9 ± 1.14; range 0 to 4) were used. Sows were moved from their gestation stall to a separate stall for filming. A digital video camera was positioned on the adjacent stall so the sows' profiles were visible. Sows were recorded for one lying-standing event. Observations ceased when the sow laid-down and stood-up or 2.5 h elapsed from recording commencement. From the video, postures and movements that occurred during the lying-standing sequences were identified. Prior to recording, sows were scored for walking lameness on a 3-point scale (1 = normal to 3 = severely lame). Time (s) from kneeling to shoulder rotation (KSR), shoulder rotation to lying (SRHQ) and total time to lie (TLIE) were determined. In addition, latency to lie (LATENCY; min) and number of attempts (ATTEMPTS) to successfully lie were recorded. Time (s) to stand was defined as the first leg fold to sit (TLS), time from sit to rise (TSR), and total time to rise (TRISE) were recorded. Sows were re-classified as non-lame (score 1) and lame (scores ≥ 2) and parity was classified as 0, 1 and 2+. Data were analyzed using mixed model methods with gestation day, parity, and lameness as fixed effects and sow as a random effect. On average, sows took 13.9 s for KSR, 7.7 s for SRHQ, 20.5 s for TLIE and 66.1 min for LATENCY. Furthermore, sows took 8.0 s for TLS, 6.9 s for TSR, and 9.8 s for TRISE. Lame sows tended to take 3.6 s longer during KSR ($P = 0.08$), and to spend 15 min less time standing ($P = 0.06$) than sound sows. Additionally, lame sows tended to be more likely to sit while transitioning from lying to standing compared with sound sows ($P = 0.07$). There were no significant associations between gestation day, lameness status or parity and lying attempts ($P > 0.05$). Results suggest that lameness scores do not greatly affect the lying-standing

sequence. However, this could be due to lameness recorded in this study not being severe enough to affect the sequences. Nonetheless, other factors such as parity seem to be related with the standing sequence timing.

Keywords: Lameness, lying sequence, sows, standing sequence

Highlights:

- Sows average 20.5 s to complete the lying process.
- Sows average 9.8 s to complete the standing process.
- Lame sows tend to spend 15 min less time standing than sound sows
- With scores observed in this study lameness does not greatly affect the lying-standing sequence in sows

1. Introduction:

Sow lameness negatively effects worker morale (Bell and Main, 2011), animal welfare (Dewey et al., 1993; Rowles, 2001; Anil et al., 2009) and economics (Dijkhuizen et al., 1989; Anil et al., 2009; Rodríguez et al., 2011). Lameness commonly causes premature culling from commercial swine breeding herds (D'Allaire et al., 1987; Stalder et al., 2004). Little information exists in the scientific literature regarding lameness etiology, severity and their relationships on sow lying-standing postural sequence profiles. Previous research into how the lying and standing process is completed began when Baxter and Schwaller (1983) outlined the lying sequence and Baxter (1984) described the standing sequences for commercial sows. Baxter (1984) suggested that locomotion ability would cause few problems, if any, to the normal lying-standing 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 these observations were supported through studies that noted lame sows had a shorter latency to lie down when compared to non-lame sows (Grégoire et al., 2013; Calderón Díaz and Boyle, 2014). Bonde et al. (2004) and Grégoire et al. (2013) reported that severe lameness increased the time (i.e. seconds taken to complete the lying sequence) to lie down. Further, Bonde and others (2004) reported that lameness in lactating sows resulted in uncontrolled lying behavior, which can increase the risk of piglet death due to crushing (Baxter and Schwaller, 1983; Blackshaw and Hagelsø, 1990; Damm et al., 2006). In addition, over the past 30-years the U.S. swine industry has focused on sow improvement through rapid genetic turnover regarding reproductive traits (Foxcroft, 2012). These improvements may have affected the sows' 3-dimensional space utilization when making postural adjustments due to changes in conformation, and size.

To our knowledge, there are no studies verbally and/or pictorially describing lying and rising postural sequences in lame and non-lame sows. Therefore, the objective of this study was to characterize the postures and movements for the lying and standing sequence in multiparous sows and identify differences between lame and sound sows, while documenting the lying and standing processes.

2. Materials and Methods

2.1. Care and Use of Animals

This study was approved by 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 located on the Bilsland Memorial Swine Breeding Farm near, Madrid, IA. Eighty-five multiparous sows (average parity 0.9 ± 1.14; range 0 to 4) were included. Gilts used represented the entire population for 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. The remaining 39 animals were cross-bred Large White × Landrace multiparous sows. Hereafter, all animals included will be referred as sows.

Sows were individually housed in gestation stalls (2.61 × 0.76 m) with fully slatted concrete flooring. The gestation barn was double curtain sided to allow for natural ventilation. Additional fans provide cooling in the summer months, and supplemental heat is provided in the winter. Sows were manually fed a gestation diet once daily that met or exceeded NRC requirements (NRC, 2012) and they were provided *ad libitum* access to water in troughs at the front of each gestation stall.

2.2. Measurements

All measures were recorded at approximately 30, 60 and 90 days of gestation. Sows were individually moved from their home stall to to a separate gestation stall with identical size (2.61 × 0.76 m) for video recording.

2.2.1. Lameness

While moving to the video recording gestation stall, sows were visually scored for walking lameness on a 3-point scale adapted from the scoring system developed by Main et al. (2000) where 1 = sow is bright, alert and responsive, sow stands squarely on all four legs and has even strides; 2 = sow is bright but less responsive (may remain lying or dog sitting before eventually rising), she is limping and has shortened stride; and 3 = sow is unwilling to leave 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:

Sows' were individually recorded for one lying down and one standing up sequence. The sow profile was continually video recorded (GoPro Hero, GoPro Inc., San Mateo, CA, USA). The camera was positioned on the adjacent gestation stall (0.76 m from the sow), approximately 50 cm from the floor. The camera was set at 1080p, and 30FPS shutter speed. Sows were video recorded between 8:00 AM and 5:00 PM. Video recording terminated once the sow had performed one lying and one standing sequence or once 2.5 h had elapsed since recording started.

Videos were first converted from mp4 to AVI format using readily available software (http://www.dvdvideosoft.com/products/dvd/Free-MP4-Video-Converter.htm). From the video, postures and movements that occurred during the lying-standing sequences were identified. ***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." Sows were classified as ***having attempted to lie down*** if either of the first two movements were observed. However, in some cases, sows were observed to begin the third movement in the sequence, but were unable to successfully slide one of their rear legs under the body, when this occurred they rapidly stood up again. In these cases, it was considered that lying had been attempted. ***Time*** from kneeling to shoulder rotation (KSR; s), time from shoulder rotation to lying (SRHQ; s), total time to lie down (TLIE; s), latency to lie down (LATENCY; min) and the number of attempts (ATTEMPTS) to successfully lie down and deviation occurrences were recorded.

Standing up was classified according to the movement sequence 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." A deviation was deemed to have occurred instead when performing the standing sequence if the sow lowered her hindquarters again and finished either sitting or lying on her sternum. ***Time*** (s) to stand was defined as the first leg fold to sit (TLS), time from sit to rise (TSR), and total time to rise (TRISE) were recorded.

2.3. Statistical analysis:

The experimental unit was the stall containing one sow. Only one sow was classified as having a lameness score 3 during 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 Table 2. All analyses were carried out in SAS v9.4 (SAS Inst., Cary, NC). 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. Sow was included as a random effect. 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. The attempts to successfully lie down were classified as 1, 2 and 3+ and they were analyzed using multinomial logistic regression in PROC GENMOD. For all logistic regression analysis, models included gestation day, lameness and parity as fixed effects, with sow included as the random effect. Results for logistic regression are reported as odds ratios (OR) with the associated 95 % confidence intervals (CI). For all analyses, statistical differences were reported when $P < 0.05$ and statistical trends were reported when $P > 0.05$ and < 0.10.

3. Results

Twenty-eight sows were removed from the trial. Four sows were moved to the Iowa State University School of Veterinary Medicine Lab Animal Research Facility before completing their pregnancies because they were diagnosed as heterozygotes for Severe Combined Immuno-Deficiency (SCID). Twenty-four sows were determined not to be pregnant by heat check. Therefore, the final number of sows' video recorded can be located in Table 1. Ninety-eight-percent of lameness was observed in the rear legs. It is important to note that only one sow was classified with a lameness score 3.

Lying down sequence: On average, sows took 13.7 s for KSR, 8.0 s for SRHQ, 20.1 s for TLIE and 61.9 min 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, LATENCY ($P = 0.06$) when compared to non-lame sows. Gestation day and parity were not associated with time allocated to different movements involved in the lying sequence ($P > 0.05$; Table 2).

There were no associations between lameness status, gestation day or parity and the likelihood of kneeling, shoulder rotation, lying or ATTEMPTS ($P > 0.05$) data not shown. Additionally, there were no significant associations between lameness status, gestation day and the likelihood to perform a deviation from the normal lying sequence ($P > 0.05$). However, sow parity 2+ tended to be less likely to deviate from the normal lying sequence when compared to gilts (OR = 0.25, 95% CI = 0.06 to 1.14; $P = 0.07$). The most common deviations observed were that the sow did not lie down in the allocated 2.5 h observation time; sows that did not rotate their shoulder and sows that finished the lying down sequence in a sitting position. Pictorial depiction of the different movement combinations observed during the lying sequence are presented in Figure 1.

Standing up sequence: On average sows took 10.3 s for TLS, 6.0 s for TSR, and 11.1s for TRISE but lameness did not affect these parameters (*P* > 0.05). Parity 1 sows had greater TLS when compared to gilts and parity 2+ (*P* < 0.05). Additionally, parity 1 sows tended to take 8.1 and 6.7 s more for TRISE than gilts and 2+ sows; respectively (*P* = 0.09). Time taken for TLS was greater at 60 d of gestation compared with 30 d and 90 d (*P* < 0.05; Table 3).

There were no significant associations between lameness status, gestation day and parity and the likelihood of performing different movements during the standing behavioral sequence (*P* > 0.05). However, lame sows tended to be more likely to sit while transitioning from lying to standing when compared to non-lame sows (OR = 1.7; 95% CI = 0.93 to 3.35; *P* = 0.07). Pictorial depictions of the different movement combinations observed during the standing sequence are presented in Figure 2.

4. Discussion

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

The time sows need to lie down in this study is similar to those reported by Marchant and Broom (1996) and Calderón Díaz and others (2014) (approximately 20 s). Contrary to our hypothesis, lameness status was not associated with time to perform lying-standing movements.

However, lame sows tended to take 2.6 s longer during KSR and to spend less time standing (i.e. 15.7 min) when compared to non-lame sows. This supports the hypothesis that the lying-standing sequence would be most likely affected only when sows are severely lame. However, as noted in this study no severely lame animals were used.

Although no differences were observed between lame and non-lame sows in the different postures adopted during the lying and standing sequences, observations from this study expand our knowledge regarding sows' lying and standing postures. Baxter and Schwaller (1983) depicted the normal lying and standing sequence with only two alternative strategies for standing; however, the images presented were convoluted and difficult to interpret. Calderón Díaz and colleagues (2015b) pictorially depicted the lying sequence for 12 sows but due to the small sample size, variations to the normal sequence were not observed except for a severely lame sow that showed uncontrolled lying down behavior. To our knowledge, this is the first time that a large number of postures and movements combination adopted during the lying and standing sequences in sows has been illustrated.

Conclusion

Lameness status was not associated with time to perform the different movements within the lying sequence. The discrepancy between our results and previous reports could be due to lameness recorded in this study not being severe enough to affect the lying sequence. However, in comparison to lameness in the industry these authors believe that consistently mild lameness seen in our sample offers an accurate representation of the sow herd, as severely lame animals are easily identified and removed by workers. In regards to the differences found in the rising sequence, the biological relevance remains unclear. The pictorial depiction for the lying and standing sequences expand our knowledge regarding different movements that occur during both processes but seem to pose no injury risk to gestating sows and, possibly to piglet survival during the lactation period; however, this requires further investigation.

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Table 1. Descriptive statistics in a study characterizing the lying-standing sequences in lame and non-lame Yorkshire and Yorkshire X Landrace sows

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	49	64	26
60 d	69	39	53	30
90 d	52	20	42	16

[a] Sows that remained pregnant and were video recorded at day 30, 60 and 90 of gestation from the profile using a go-pro Hero 4 camera attached to the adjacent gestation stall.

[b] Sows that were classified as lame or non-lame on a 0 1 scale adapted from Main et al., 2000 from the total number video recorded per observation.

[c] Sows that performed the lying and standing behavior as defined by Baxter and Schwaller (1983) and Baxter (1984) at gestation day 30, 60 and 90.

[d]Lame sows that performed the lying and standing behavior at gestation day 30, 60 and 90

Table 2. Time to perform lying sequence[1] movement differences (LS means ± SE) between lame and non-lame multiparous Yorkshire and crossbred sows at 30, 60 and 90 days of gestation.

Variables	Time from Kneeling to shoulder rotation[1], s (KSR)		Time from shoulder rotation to lower hindquarter[1], s (SRHQ)		Total time to lie down[2], s (TLIE)		Latency to lie down[3], min (LATENCY)	
	LS means	±SEM	LS means	±SEM	LS means	±SEM	LS means	±SEM
Lameness[4]								
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[5] (d)								
30	11.3^{a}	± 1.57	8.1^{a}	± 0.84	18.9^{a}	± 1.51	66.1^{a}	± 6.43
60	12.9^{a}	± 1.69	7.2^{a}	± 0.94	19.1^{a}	± 1.65	64.7^{a}	± 6.90
90	16.8^{a}	± 2.12	8.1^{a}	± 1.09	22.2^{a}	± 2.09	54.9^{a}	± 8.57
Parity[6]								
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

Table 2 Continued

2+	12.7[a]	± 2.35	9.6[a]	± 1.34	21.4[a]	± 2.07	66.5[a]	± 9.42

[1]Lying was defined as three sequence movements that have been previously described by Baxter (1984) 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 sequence from kneeling position to lowering the hindquarters and finishing in either ventral or lateral recumbency

[3]Total time standing determined from observation begins until sow successfully lies down or 2.5 hours

[4]Lameness was classified as 0 (non-lame) or 1 (lame) on a scale adapted from Main et al. (2000)

[5]Observations were done at approximately 30, 60 and 90 days of gestation

[6]Parity was re-classified as 0, 1 or 2+ as sow number for parity larger than 2 was small

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

Table 3. Time to perform standing sequence[1] movement differences (LS means ± SE) between lame and non-lame multiparous Yorkshire and Yorkshire X Landrace at days 30, 60 and 90 of gestation.

	Time from leg-fold to sit[1], s (TLS)		Time from sitting to rise up[1], s (TSR)		Total time to rise up[2], s (TRISE)	
Variables	**LS means**	**±SEM**	**LS means**	**±SEM**	**LS means**	**±SEM**
Lameness[3]						
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[4] (d)						
30	8.5[b]	± 2.47	8.4[a]	± 1.66	12.2[a]	± 2.14
60	15.9[a]	± 2.77	4.6[a]	± 1.91	11.9[a]	± 2.39
90	6.5[b]	± 3.67	4.9[a]	± 2.44	9.1[a]	± 2.76
Parity[5]						
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

Table 3 Continued

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]Lameness was classified as 0 (non-lame) or 1 (lame) on a scale adapted from Main et al. (2000)

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

[5]Parity was re-classified as 0, 1 or 2+ as sow number for parity larger than 2 was small

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

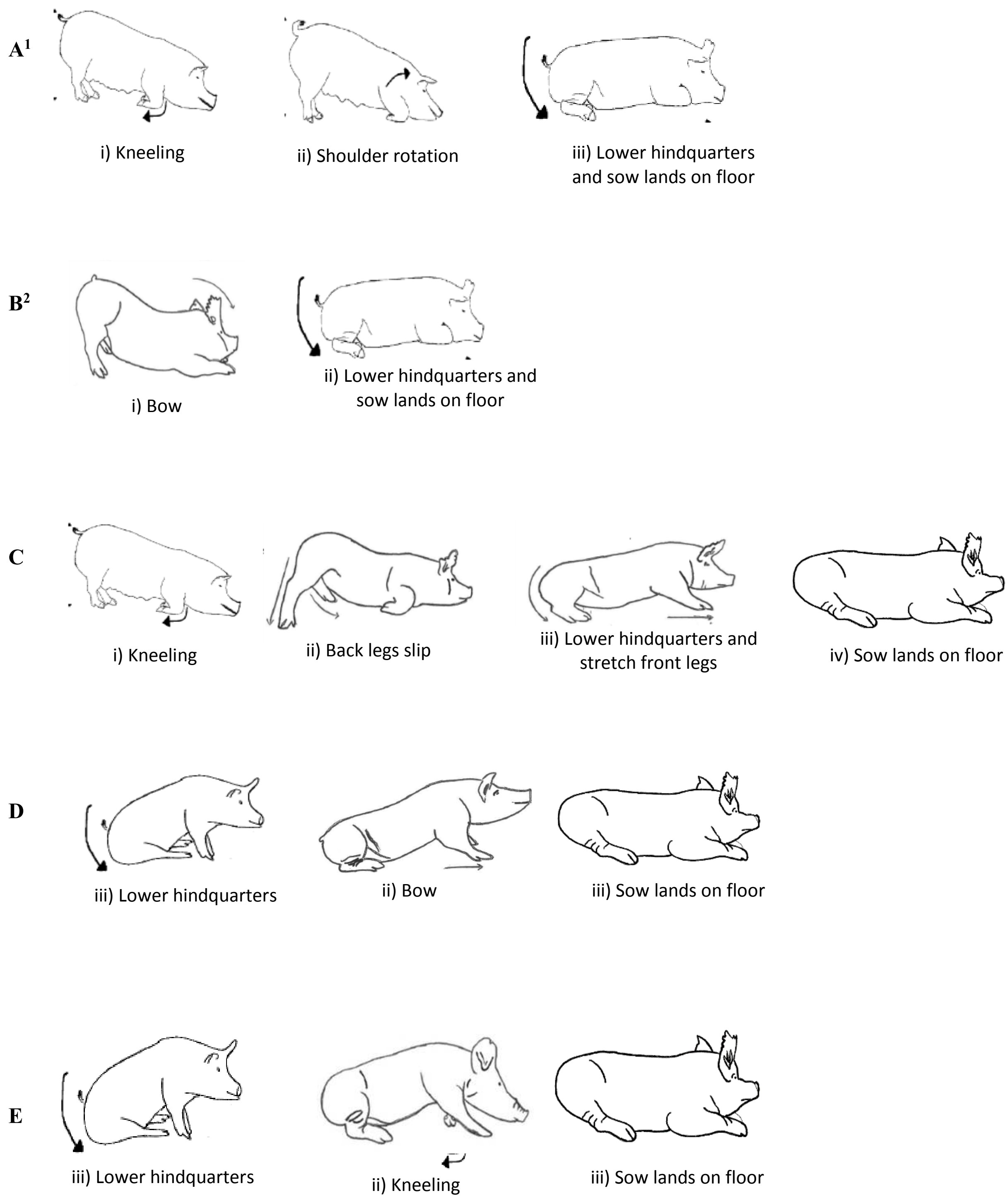


Figure 1. Different combinations of movements observed during the lying down sequence. A) Normal lying down sequence as described by Baxter and Schwaller (1983)., B to H represent deviations from the normal lying down sequence.

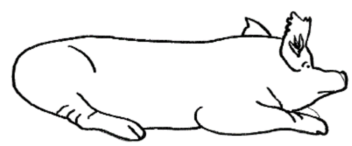
F

i) Kneeling

ii) Lower hindquarters and sow lands on floor

G

i) Lower hindquarters



ii) Sow lands on floor

H

i) Lower hindquarters

Figure 1 Continued

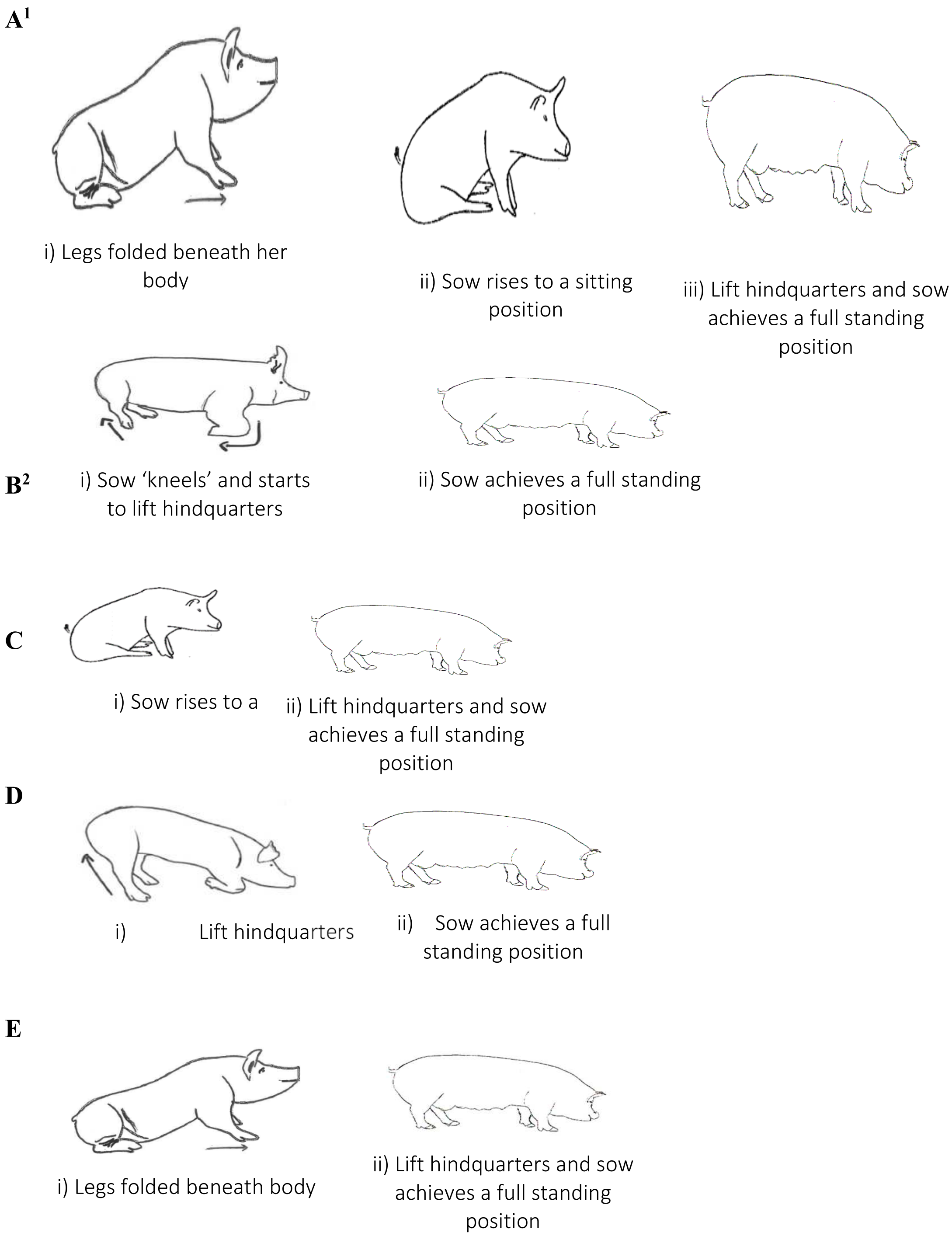


Figure 2. Movement combinations observed during the standing sequence.

A) Normal standing up sequence as described by Baxter (1984)., B to E represent deviations from the normal standing up sequence.

CHAPTER V: SUMMARY AND CONCLUSIONS

` Building design, space requirements, and stocking densities are aspects that influence production capabilities and have traditionally been calculated from static space measurements. However, swine need both static and dynamic space considerations and this later measure is very sparse in the current scientific literature. The European Union, having banned the use of gestation stalls and mandated group housing for gestating swine provides space requirements for sows and gilts (Council of the European Union, 2008). In the U.S. sow housing recommendations are made based on how the sow interacts with her confinement, (i.e. she must easily lie down on her side without her head resting on the feeder or her hindquarters touching the rear of the stall), and group housing recommendations are similarly vague where viewing the sow in regards to her environmental confines are the only determining factors for space (Swine Care Handbook, 2016).

An objective of this thesis was to quantify sow dynamic space requirements when afflicted with lameness at various stages of production and age when standing and lying. The calculated dynamic space is similar to these accepted measures from the European Union, and can be used as a benchmark for the U.S. sow herd moving forward as a potential extension resource, and also legislation based on swine housing.

This thesis also evaluated the lying and standing differences or lame and non-lame sows along with the dynamic space utilization. In 1983 Baxter and Schwaller published the pictorial depiction of the lying and standing process of sows. Given the changes that have taken place in the swine herd since then, a goal of this work was to revisit these postural alterations and create verbal and pictorial representation of these postural sequences. The confined sows' lying and standing process is important as it can be considered as a limited form of exercise (Marchant and Broom, 1996). The movements become of paramount importance in farrowing and lactation because uncontrolled, quick movements can inadvertently result in an increase in piglet crushing (Damm et al., 2006; Barnett et al., 2001). These initial data sets provide the foundation to next detail how the types of lameness etiologies affect the standing-lying postural sequences. Similarly, the depictions presented herein, offer a more comprehensive representation of the lying and standing process than has been previously recorded and are a useful tool for potential on-farm use.

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