Stavrakakis S, Guy JH, Syranidis I, Johnson GR, Edwards SA.

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The Veterinary Journal 2015, 205(1), 38-43.

DOI link to article:

http://dx.doi.org/10.1016/j.tvjl.2015.04.022

Date deposited:

25/02/2016

Embargo release date:

23 April 2016

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PII: S1090-0233(15)00164-1
DOI: http://dx.doi.org/doi:10.1016/j.tvjl.2015.04.022
Reference: YTVJL 4491

To appear in: *The Veterinary Journal*

Accepted date: 16-4-2015

Pre-clinical and clinical walking kinematics in female breeding pigs with lameness: A nested case-control cohort study

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Highlights

- Gait kinematics of replacement gilts were evaluated before and during visually diagnosed lameness in a long-term study.
- Relative, rather than absolute, gait measures were identified as the best quantitative clinical lameness indicators.
- Some spatiotemporal gait parameters were better than others for detection and evaluation of gait abnormalities.
- The step-to-stride length ratio was altered in pre-clinical pigs and may be used as an early predictor for lameness.

Abstract

Gait profiles were investigated in a cohort of female pigs experiencing a lameness period prevalence of 29% over 17 months. Gait alterations before and during visually diagnosed lameness were evaluated to identify the best quantitative clinical lameness indicators and early predictors for lameness. Pre-breeding gilts (*n* = 84) were recruited to the study over a period of 6 months, underwent motion capture every 5 weeks and, depending on their age at entry to the study, were followed for up to three successive gestations. Animals were subject to motion capture in each parity at 8 weeks of gestation and on the day of weaning (28 days postpartum). During kinematic motion capture, the pigs walked on the same concrete walkway and an array of infra-red cameras was used to collect three dimensional coordinate data of reflective skin markers attached to the head, trunk and limb anatomical landmarks.

Of 24 pigs diagnosed with lameness, 19 had preclinical gait records, whilst 18 had a motion capture while lame. Depending on availability, data from one or two preclinical motion captures 1-11 months prior to lameness and on the day of lameness were analysed.

Lameness was best detected and evaluated using relative spatiotemporal gait parameters, especially vertical head displacement and asymmetric stride phase timing. The step-to-stride length ratio was elevated (deviation ≥ 0.03) in young pigs which presented lameness in later life (odds ratio 7.2-10.8).

Keywords: Sow; Biomechanics; Motion analysis; Lameness

Introduction

Lameness has an impact on the health, welfare and production economics of sow herds (Heinonen et al., 2013; Willgert et al., 2014). The reported prevalence of lameness among gilts and sows ranges from 5% to 20%, depending on the assessment method, production system and genotype (KilBride et al., 2009; Nalon et al., 2013). Lameness is a clinical sign defined by observable changes in gait (Weishaupt, 2008). Whilst degenerative joint disease and associated leg weakness is the predominant cause of lameness in growing pigs, secondary degenerative changes and infectious arthritis are the most common causes in sows (Dewey et al., 1993; Kirk et al., 2005). Group housing systems for breeding females appear to increase the prevalence of lameness (Spoolder et al., 2009). Claw lesions are widely observed in sows, but their presence does not sufficiently explain the level of lameness observed (Pluym et al., 2011; Grégoire et al., 2013).

Subjective gait scoring protocols are currently the only on-farm tool available for the quantification of lameness (Main et al., 2000; de Koning et al., 2012), but these have low repeatability (Petersen et al., 2004). Subtle lameness is difficult to detect and evaluate (D’Eath, 2012), and is costly and time-consuming to observe (Nalon et al., 2013), especially since there is a need to examine a substantial number of animals to obtain accurate estimates of the prevalence of lameness (Mullan et al., 2009).

Identification of biomechanical parameters of locomotion could provide an objective means of identifying animals with lameness (Sun et al., 2011; Karriker et al., 2013), improve our understanding of disease of the musculoskeletal system and enable detection of animals with otherwise unobservable abnormalities. Herds could benefit from the development and implementation of automated and continuous on-farm lameness monitoring systems (Keegan 2007; Cornou et al., 2008).

The aims of this study were: (1) to determine characteristic movement changes in gilts and sows with clinical lameness based on an analytical biomechanical method, i.e. lameness detection, and (2) to determine whether gait characteristics in pre-breeding gilts could predict subsequent lameness, i.e. lameness prediction. It was hypothesised (1) that there would be similar changes in the kinematics of lame pigs, regardless of affected limb(s); (2) that simultaneous consideration of two or more quantitative gait variables could indicate the site of lameness, and (3) that early gait records of pigs that developed lameness at a later time point could be differentiated from control pigs that were consistently sound during the study period. It was assumed that the majority of the diagnosed lameness would be due to chronic and previously latent abnormalities and not due to injuries or infections in an otherwise healthy musculoskeletal system.

Materials and methods

Animals

All procedures on animals were undertaken in accordance with institute guidelines and UK animal welfare regulations (ERC project number 274, date of approval 17 May 2011). The experimental cohort consisted of 84 pre-breeding Large white × Landrace gilts from the Newcastle University pig unit. Gilts were recruited to the study from January 2011 to July 2012. At the time of entry to the study, the youngest batch of gilts weighed on average 39 ± 3.8 kg (mean ± standard deviation, SD) and the oldest weighed 146 ± 13 kg.

Data collection

Pigs were initially habituated to close human contact and learned to follow a human operator to obtain a small piece of apple as a reward when movement was regular, continuous and straight. Motion capture was initially applied to the same pigs every 5 weeks to build a data base of gait development during growth from initial selection, typically at 40 kg bodyweight (BW) or 4 months of age, to the point of insemination, typically at 140 kg BW or 8 months of age. The median number of motion captures for pre-breeding gilts was three (range 1-5). Subsequently, each pig underwent motion capture in mid-gestation (typically at 8 weeks after insemination) and on the day of weaning (after 28 days of lactation) during each parity. The study was terminated in July 2013, at which point the oldest sows had weaned their third litter.

A kinematic reflective marker model with motion capture was applied to the pigs over key anatomical landmarks and captured with a T20 six camera three-dimensional (3D) system (Vicon), providing full body kinematics of one body side at a time (Stavrakakis et al., 2014a, b).

Lameness was clinically diagnosed using a subjective scale adapted from Main et al. (2000) immediately after motion capture as follows: 0, normal; 1, stiffness; 2, reduced weight bearing; 3, minimal weight bearing; 4, limb not used while moving; 5, animal does not move. Animals with scores of 4 and 5 were not subjected to motion capture. The period prevalence of lameness was defined as the proportion of the total number of animals recorded with clinical lameness at any point during the 17 month study, whilst period incidence was defined as the number of separate clinical cases of lameness which occurred within the study period, with several animals counted repeatedly. Attempts were made to achieve a tentative diagnosis of the cause of lameness. Pressure tests including palpation of all joints in the affected limbs(s) were made, as well as an assessment of a number of leg weakness traits (Table 1). A general impression of hoof health, shape and size was also recorded.

Data processing

Of the 24 females showing clinical lameness (i.e. score ≥ 2 at any time point), 19 had preclinical motion capture records from the pre-breeding stage and 18 had a usable motion capture while lame. Of the others, three were already lame at the first pre-breeding motion capture and two had no usable early motion capture data.

To identify biomechanical indicators of clinical lameness in gilts and sows, the gait data of the 18 gilts or sows with lameness were grouped according to site of lameness and compared with data from sound control pigs, matched to production stage and BW.

To identify predictors of lameness, early gait records of pre-breeding gilts which subsequently developed lameness (preclinical pigs; n = 19), were separated into two BW groups, generating two separate data sets, i.e. 63 kg median BW gilts (range 45-77 kg; n = 13) and 97 kg median BW gilts (range 84-123 kg; n = 11). This approach enabled the recruitment of at least 10 subjects per BW group. Although most pigs developing lameness appeared only once in a particular BW category, five pigs appeared in both BW groups due to a second pre-breeding record prior to lameness. Gait data from sound control pigs matched by BW, but with no perceived gait abnormality throughout the study period, were used for comparison.

Coordinate data were exported from motion capture software (Vicon Nexus, Version 1.7.1) and imported into Matlab (Mathworks, Version R2010b). Data were processed using a custom written programme for stride event detection and gait parameter calculation (Stavrakakis et al., 2014b).

Data analysis

Angular, temporal and spatial kinematics were analysed for differences across groups. Within subject means were created for every gait parameter and capture, and included left and right body sides (i.e. total session means). Front and hind limb gait parameters were analysed separately, except for stride lengths. To assess asymmetry, differences between left and right side measures, or the within session SD, were considered in addition to the mean gait parameter.

To exclude factors that might cause differences in gait other than those under investigation, all compared groups (Tables 2–6; see Appendix: Supplementary material) were checked for absence of differences in size (BW, limb length) and walking speed. The data were not normally distributed and therefore Mann-Whitney tests were used to compare cases and their matching control groups (Minitab version 16).

If gait is perfectly symmetrical, step length is half the stride length, so that the step-to-stride length ratio is 0.5. Thus, deviation from perfect symmetry, using a value for the step-to-stride length ratio of 0.03 as a threshold deviation, was determined for individual pigs. These were then classified as having either normal or abnormal gait, and either future or no future lameness.

Results

Lameness

Bodyweight, limb length and walking speed were not significantly different between lame pigs and their matched controls. Over the 17 months, there were 33 cases of lameness in 24/84 (29%) animals. Lameness affected 14 pre-breeding gilts, six gilts in mid-pregnancy, one gilt during lactation and three gilts in their second gestation. Over the course of the study, two gilts were euthanased due to severe bilateral hind limb lameness and 17 were culled due to reproductive failure. Lameness severity scores were similar between pre-breeding animals (mean ± SD lameness score 2.6 ± 0.74) and breeding animals (2.4 ± 0.52).

Clinical diagnosis of the affected limb(s) was possible in all but five cases, where either multiple limbs were involved or the site of lameness could not be determined. In general, lameness did not appear to originate from the claws and there were no obvious clinical signs of infection and inflammation. The repeated occurrence of lameness in some animals and the relatively high prevalence among the maturing gilts supports the idea that clinical lameness was a result of chronic, degenerative joint abnormalities.

Angular kinematics during clinical lameness

Table 2 shows joint flexion differences detected in pigs with lameness compared to sound control pigs. Stifle flexion was increased in pregnant gilts with lameness of uncertain origin (median difference +4°; $P = 0.02$), but was not increased in pre-breeding gilts with hind limb lameness ($P = 0.06$). There was no significant difference in joint flexion between left and right stifles of pregnant gilts with lameness of uncertain origin ($P = 0.08$).

Temporal kinematics during clinical lameness

In general, the differences between left and right hoof stance times, swing times and duty factors within a pair of limbs, were greater for lame pigs than for controls (Table 3).

Pigs lame in a front limb had increased front limb pair asymmetry, but no hind limb asymmetry, while pigs lame in a hind limb displayed asymmetry in both limb pairs. Pigs with unclear or multiple limb lameness had greater hind limb asymmetry, but no significant differences in symmetry between front limbs. Overall, absolute stance time was not increased in lame pigs for affected or unaffected limbs, or both, except for pigs with hind limb lameness where stance time was increased in hind limbs only (see Appendix: Supplementary material).

Spatial kinematics during clinical lameness

Median vertical head displacement within stride was increased (+15-38 mm; $P \leq 0.05$; Table 4) in all lame groups, shown as a characteristic head bob. The most substantial increase was observed in pigs with front limb lameness (Fig. 1), with all such pigs having a vertical head displacement > 54 mm. This threshold was value was exceeded in 6/12 pigs lame in the hind limbs or in multiple limbs, so is not only indicative of front limb lameness. Specificity and sensitivity of the 54 mm head bob threshold were 100% and 67%, respectively.

There was a small increase in spine vertical displacement during the swing phase in pigs with front and hind limb lameness (+6-7 mm; $P \leq 0.05$; Table 4). Pigs with unidentified or multiple limb lameness had greater lateral pelvic displacement (+10 mm; $P \leq 0.05$; Table 4) during the stance phase. While 80% of all pigs with unidentified or unclear lameness had a lateral pelvic displacement greater $\geq$ 41 mm, 17% and 29% of pigs lame in front and hind limbs, respectively, and 18-29% of sound control pigs also crossed this threshold. Specificity and sensitivity of this pelvic sway threshold were 80% and 38%, respectively. Step width variability was increased in some cases, but the actual step width magnitude was not consistently affected (Table 4). Stride length was not different in lame pigs, but the step-to-stride length ratio was affected in all pigs with single limb lameness.

Lameness prediction from early gait records

In the early data sets of both 63 kg and 97 kg BW groups the step-to-stride length ratio deviation from 0.5 (perfect symmetry) was ≥ 0.03 for pigs which subsequently developed lameness 1 to 11 months later (Table 5). Compared to sound control pigs, deviation in the step-to-stride length ratio was observed either in front limbs alone or the mean of front and hind limbs. Compared to sound control pigs, the difference was greater by 0.007 and 0.01 for the 63 kg and 97 kg BW groups, respectively. Odds ratios, sensitivities and specificities of the step-to-stride length ratio are shown in Table 6.

Discussion

Few studies have provided a detailed analysis of movement changes in pigs associated with clinical lameness (Grégoire et al., 2013; Nalon et al., 2013). The present study provides both a detailed analysis of limb specific subjective and objective gait changes due to lameness and an assessment of using early biomechanical assessment to predict future lameness. The methodology used in this study was time-consuming, typically taking about 2 h per animal for motion capture and initial data processing. However, whilst this study used an elaborate motion analysis system to obtain whole body kinematics, in the future simpler systems could be used to measure specific gait parameters.

Increased stifle flexion in some pigs affected with lameness may indicate that there was a predominant problem at this or a neighbouring joint. However, further research is needed to determine whether changes in flexion during biomechanical assessment can be related to the underlying cause of the lameness. In particular, it would be of value to determine whether gait analysis could discriminate between causes of lameness such as bacterial arthritis, which can be treated with antibiotics, and degenerative arthrosis which does not respond to antibiotics. For example, using rats in which arthritis had been induced, Boettger et al. (2009) showed that gait abnormalities differentially indicated pain or structural joint damage.

Although Grégoire et al. (2013) reported that lame pigs had longer stance times, in the present study lame pigs often showed a shorter stance time of affected limb(s) than controls. However, lame pigs had longer stance times of contralateral and diagonally opposite unaffected limbs, reflected in the difference in the ipsilateral swing/stance time ratio. There were also substantial differences between the swing times of affected and unaffected limbs, which were even greater than the differences in stance times. This is in agreement with data from horses, for which reduced swing times are one of the most consistent findings of supporting limb lameness (Back and Clayton, 2001). Reduced impulse during the stance phase can lead to reduced propulsion of affected and unaffected limbs. However, while lame horses often maintain gait symmetry in limb pairs, lame cows and pigs display asymmetry (van Nuffel et al., 2009; Duberstein et al., 2014).

Differences between the same measure in left and right limbs, the overall within limb pair SD of a given gait parameter and the ratio of two variables with the same unit consistently differentiated lame from control pigs. The effects of lameness on these relative measures were often quite pronounced, e.g. median values were 2-4 times higher than for controls. However, while the pattern of such differences varied between pigs with lameness in different limbs and control pigs, most of the parameters did not differentiate between pigs which had lameness in different parts of the body. This suggests that there were considerable compensatory changes in unaffected limbs (Pluym et al., 2011) and that different pigs may employ different compensatory strategies to compensate for a lame limb.

Absolute stance time, stride length and walking speed generally were not different between lame and sound control pigs. study pigs were expecting a treat and may have been more motivated to walk even when lame, which may explain why a lower walking speed was not observed (Bos et al., 2013). Furthermore, the category of lame pigs comprised animals with both reduced weight bearing and minimal weight bearing abilities, a category which Grégoire et al. (2013) had separated into mildly lame and lame pigs, respectively. Thus, in the current study, combining the severities of lameness into a single category probably led to an increase in the variability of walking speed. However, a decrease in stride length and an increase in stance time can be associated directly with a decrease in walking speed (Kirtley et al., 1985; Walker et al., 2010).

The vertical displacement of the head was increased in 67% of all lame pigs and in 100% of pigs with front limb lameness. This agrees with Mustonen et al. (2011), who also referred to head bobbing in pigs as an advanced lameness indicator, but disagrees with Main et al. (2000) who argued that, with their short neck, pigs have a limited capability to compensate for lameness with changes in frontal body movement. It is possible that the relative change in vertical head displacement in pigs is smaller than in sheep and horses (Weishaupt, 2008; Kaler et al., 2009). Nonetheless, head bobbing was one of the most important clinical indicators of lameness in the present study, especially in lameness associated with the front limb.

Another important finding of this study was the predictive value of the step-to-stride length ratio. In this study, the step-to-stride length ratio was independent of pig size, liveweight and walking speed, consistent with the results of the longitudinal study reported by Stavrakakis et al. (2014b). However, irregularity in step-to-stride length ratio can increase with instantaneous acceleration or deceleration during walking, and when an animal does not walk in a straight line. Although these effects could only be partly quantified in the present study, they were mainly noted during data processing. For example, one outlier among the control pigs was a particularly nervous animal, whilst an outlier among the preclinical pigs was an individual which had only a small deviation from 0.5, but was subsequently diagnosed with lameness due to toe wall separation.

Unfortunately, since the cause of lameness was not determined in this study, extracting only those cases with a preclinical biomechanical disturbance, such as chronically developing degenerative joint lesions and weakness in the muscle-tendon structures, was not possible. It is also possible that there were false negatives within the control pigs, as some pigs might have developed lameness after the study ended.

In the 63 kg BW group, median step-to-stride length ratio deviation for front and hind limbs was a significant lameness predictor, whereas in the 97 kg BW group, only deviation in the front limb ratio was significant. Therefore, step-to-stride length ratios should be calculated separately for front and hind limbs and not be pooled. Prediction of the limb pair in which lameness would occur based on step-to-stride length ratio deviation was successful in approximately half the cases. Whether irregularity in the step-to-stride length ratio is a primary or a secondary compensatory change in walking patterns needs to be clarified, as does whether the irregular step-to-stride length ratio has different causes in different pigs.

Conclusions

This study showed that monitoring of relative gait measures could reliably detect lameness in pigs. The step-to-stride length ratio could identify up to 74% of the pigs which subsequently developed lameness. Gait measurements may be more successful than subjective classification in targeting longevity characteristics of pigs and assessing the risk of subsequent development of lameness. Furthermore, biomechanical gait analysis may help to standardise lameness assessment.

Conflict of interest statement

None of the authors of this paper has a financial or personal relationship with other people or organizations that could inappropriately influence or bias the content of the paper.

Acknowledgements

The authors are grateful to the British Pig Executive (BPEX), a division of the Agriculture and Horticulture Development Board, for funding this project. Furthermore, we thank the University of Newcastle farm team for their support, especially Mark Brett for providing expertise in animal training and invaluable assistance during motion captures.

Appendix: Supplementary material

Supplementary data associated with this article can be found, in the online version, at doi: setters please insert doi number

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Figure legend

Fig. 1. Vertical head displacement changes during clinical lameness. (a) Pig lame in the left front (LF) limb showing increased vertical head displacement within stride, i.e. significant head bob. The head is lifted at the instant of impact of the lame limb. (b) Sound control pig with regular head movement. (c) Comparison of vertical head movement in two sound control pigs of different size with that for one lame pig. The lower solid and dashed lines are the vertical trajectories of lame and sound front hoofs, respectively, of the lame pig. The vertical dashed lines enclose a plateau representing the stance phase of the affected limb and the corresponding head displacement phase above (solid red line). Also note how the swing phases (peaks of the lower trajectories) of the two hoofs are different, i.e. the sound hoof dashed trajectory has a much sharper peak and mimics the trajectory of the head.

Table 1

Leg weakness traits adapted from Jørgensen and Andersen (2000).

Characteristic	Deficiency	Description
Alignment of front and hind limbs	Buck-kneed	Front limbs buckling forward
	Sickle-hocked	Excessive bending of hind limbs at hock
	Post-legged	Excessive straightness
	Splay–footed	Toes/limbs turned out
	Pigeon-toed	Toes/limbs turned in
	Varus	O-shaped frontal profile of front or hind pair
	Valgus	X-shaped lateral profile of front or hind pair
Spine	Kyphosis	Humped back
	Lordosis	Broken back
Hooves	Weak pastern	Pastern touching ground
	Upright pastern	Pastern angle too steep

Unevenness	Uneven claws of hoof

Table 2

Descriptive statistics of joint flexion in pigs with clinical lameness (reduced or minimal weight bearing) categorised as being either in front limb, hind limb or multiple limbs/unclear compared to non-lame control pigs.

		Lame pigs (*n* =18)			Non-lame control pigs (*n* = 44)		
		Front limb	Hind limb	Multiple limbs/Unclear			
		Gilts	Gilts	Pregnant gilts	Gilts	Gilts	Pregnant gilts
		140 kg	137 kg	210 kg	94 kg	138 kg	206 kg
Joint	Gait parameter (degrees flexion)	(*n* = 6)	(*n* = 7)	(*n* = 5)	(*n* = 11)	(*n* = 17)	(*n* = 16)
Knee joint	Asymmetry[d]	6^{ab}	5^{ab}	6^{a}	4^{ab}	4^{ab}	3^{ab}
	Flexion[e]	66^{abc}	71^{a}	69^{a}	65^{bc}	68^{ab}	65^{bc}
Elbow joint	Asymmetry	4^{a}	4^{a}	3^{a}	5^{a}	5^{a}	5^{a}
	Flexion	71^{a}	71^{a}	68^{ab}	71^{a}	68^{ab}	66^{b}
Carpal joint	Asymmetry	1^{a}	1^{a}	1^{a}	1^{a}	1^{a}	1^{a}
	Flexion	8^{a}	9^{ab}	9^{ab}	10^{b}	10^{ab}	10^{ab}
Tarsal joint	Asymmetry	7^{ac}	8^{a}	2^{b}	3^{bc}	5^{ac}	3^{bc}
	Flexion	33^{a}	36^{a}	35^{a}	34^{a}	34^{a}	33^{a}

Medians are displayed. Note that gilts at 94 kg are included on an equal walking speed/stride length basis (see Table 4).

[a,b,c] Medians within a row not sharing superscripts differ significantly at $P \leq 0.05$. Mann Whitney tests were used.

[d] Mean asymmetry between left and right body sides for flexion extremes (minimum and maximum joint flexion) during stance and swing phases of the gait cycle.

[e] Mean of flexion extremes during stance and swing phases of the gait cycle including left and right body side.

Table 3

Descriptive statistics of the temporal gait parameters of pigs with clinical lameness (reduced or minimal weight bearing) categorised as being either in front limb, hind limb or multiple limbs/unclear compared to normal control pigs.

		Lame pigs (*n* = 18)			Non-lame control pigs (*n* = 44)		
		Front limb	Hind limb	Multiple limbs/Unclear			
		Gilts	Gilts	Pregnant gilts	Gilts	Gilts	Pregnant gilts
		140 kg	137 kg	210 kg	94 kg	138 kg	206 kg
Limbs	Gait parameter: Asymmetry[d]	(*n* = 6)	(*n* = 7)	(*n* = 5)	(*n* = 11)	(*n* = 17)	(*n* = 16)
Front	Stance time (s)	0.035[a]	0.048[a]	0.023[ab]	0.025[b]	0.014[b]	0.017[b]
	Swing time (s)	0.044[a]	0.047[ab]	0.055[a]	0.018[bc]	0.010[c]	0.016[c]
	Duty factor (%)	4.9[a]	4.8[a]	3.1[ab]	2.3[bc]	1.3[bc]	1.4[bc]
Hind	Stance time (s)	0.016[b]	0.059[a]	0.071[a]	0.013[b]	0.017[b]	0.021[b]
	Swing time (s)	0.029[ac]	0.071[b]	0.044[ab]	0.010[c]	0.018[c]	0.018[c]
	Duty factor (%)	2.1[ac]	6.8[b]	4.6[ab]	1.5[c]	2.1[c]	1.8[c]
Ipsilateral	Swing/stance time ratio	0.21[ab]	0.30[a]	0.09[bc]	0.04[c]	0.08[bc]	0.03[c]

Medians are displayed. The duty factor is stance time/(stance+swing time)*100. Note that gilts at 94 kg are included on an equal walking speed/stride length basis (see Table 4).

[a,b,c] Medians within a row not sharing superscripts differ significantly at $P \leq 0.05$. Mann Whitney tests were used.

[d] Asymmetry as defined by the difference between the same parameter measured on left and right body sides.

Table 4

Descriptive statistics of the spatial gait parameters of pigs with clinical lameness (reduced or minimal weight bearing) categorised as being either in front limb, hind limb or multiple limbs/unclear compared to normal control pigs.

			Lame pigs (*n* = 18)			Non-lame control pigs		
			Front limb	Hind limb	Multiple limbs/Unclear			
			Gilts	Gilts	Pregnant gilts	Gilts	Gilts	Pregnant gilts
			140 kg	137 kg	210 kg	94 kg	138 kg	206 kg
Body part	Gait parameter: displacement (mm)	Gait phase	(*n* = 6)	(*n* = 7)	(*n* = 5)	(*n* = 11)	(*n* = 17)	(*n* = 16)
Head	Vertical	Stance	70^{a}	52^{a}	65^{ac}	31^{b}	32^{b}	38^{c}
		Swing	70^{a}	51^{a}	49^{ab}	30^{bc}	30^{bc}	34^{bc}
Spine	Vertical	Stance	22^{a}	24^{ab}	18^{ab}	19^{ab}	21^{ab}	20^{ab}
		Swing	25^{a}	24^{ac}	19^{ab}	18^{b}	18^{b}	19^{bc}
Pelvis	Lateral	Stance	31^{ad}	38^{abd}	42^{b}	30^{cd}	29^{ac}	32^{ac}
		Swing	36^{abe}	41^{abe}	39^{abe}	31^{bc}	39^{acd}	41^{de}
All limbs	Stride length		750^{abc}	801^{abcd}	776^{abcd}	778^{b}	816^{c}	872^{d}
	Walking speed (mm/s)		890^{ab}	837^{ab}	836^{ab}	849^{a}	942^{b}	935^{ab}
Front limbs	Step height		54^{abc}	60^{ac}	78^{ab}	50^{c}	58^{abc}	64^{ab}
	Step width		147^{abd}	162^{bd}	156^{bd}	117^{c}	130^{abc}	163^{d}
	Step width standard deviation		27^{a}	28^{a}	30^{a}	25^{a}	27^{a}	25^{a}
Hind limbs	Step height		61^{abd}	62^{ad}	70^{abe}	48^{c}	54^{cd}	65^{e}
	Step width		128^{ad}	123^{acd}	155^{bd}	103^{ac}	116^{acd}	144^{d}
	Step width standard deviation		41^{ab}	41^{a}	30^{bc}	22^{cd}	25^{cd}	26^{bd}
Front limbs	Step/stride length ratio deviation from 0.5		0.067^{a}	0.028^{ab}	0.021^{abc}	0.020^{b}	0.018^{b}	0.021^{bc}
Hind limbs	Step/stride length ratio deviation from 0.5		$0.034^{a(c)}$	0.042^{ac}	0.032^{ab}	0.024^{bc}	0.019^{b}	0.25^{b}
Both pairs[d]	Step/stride length ratio deviation from 0.5		0.049^{a}	0.041^{a}	0.026^{ab}	0.023^{b}	0.019^{b}	0.25^{b}

Medians are displayed. Gilts at 94 kg are included as a control group on an equal walking speed/stride length basis.

[a,b,c] Medians within a row not sharing superscripts differ significantly at P≤0.05. Mann Whitney tests were used.

[d] (Front limbs deviation + Hind limbs deviation)/2.

Table 5

Irregularity in the step-to-stride length ratio, measured as deviation from 0.5 (perfect symmetry) in early gait records of pigs presenting with lameness 1 to 11 months later.

	Pigs developing lameness (n = 19[d])		Sound control pigs			
	Gilts	Gilts	Gilts	Gilts	Gilts	Pregnant gilts
	63 kg	97 kg	60 kg	96 kg	130 kg	206 kg
Limbs	(n = 13)	(n = 11)	(n = 11)	(n = 10)	(n = 13)	(n = 10)
Front limbs	0.028[ab]	0.030[ab]	0.026[bc]	0.020[c]	0.018[c]	0.021[c]
Hind limbs	0.029[a]	0.026[a]	0.023[a]	0.024[ab]	0.019[b]	0.025[ab]
Both limbs	0.031[a]	0.028[ab]	0.024[bcd]	0.023[bcd]	0.019[d]	0.025[bd]

All pigs were clinically classed as showing no lameness/good locomotion on days of capture; control pigs never developed lameness during the 17 months follow-up period. Normal control pigs were matched for size, weight and age. Medians are displayed. Older control pigs are added to demonstrate time effect on the ratio.

[a,b,c] Medians within a row not sharing superscripts differ significantly at $P \leq 0.05$ using Mann-Whitney tests.

[d] Five animals appear in both size groups due to a second early record before lameness.

Table 6

Step-to-stride length ratio deviation from 0.5 (perfect symmetry) as a diagnostic measure of future lameness using a threshold value of 0.03 and considering lower values as normal.

	Gilts	Gilts	Gilts [b]	Gilts
	60-63 kg	96-97 kg	60-97 kg gilts	60-97 kg[b,c]
	Mean of front and hind limb deviation[a]	Front limb deviation only	Mean of front and hind limb deviation[a]	Front and hind limb deviation
Odds ratio	7.2	10.8	2.8	5.6
Sensitivity (%)	62	55	58	74
Specificity (%)	82	90	67	67

[a] Mean of front and hind limb deviation includes that both measures together can be < 0.03, even if one measure was originally higher.

[b] This included preclinical and respective controls (n = 40) as in Table 5 for the two time points together; the second record was used for gilts with two early records (n = 5); the value of the measure in a pooled scenario is herewith demonstrated.

[c] Both front and hind ratio deviations had to be < 0.03 for a pig to be considered normal.