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GAIT AND FORCE ANALYSIS METHODS APPLIED IN PIG GAIT RESEARCH

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ABSTRACT Claw injuries, leg weakness, or locomotor disorders are common problems in pigs. These disorders have been documented in scientific research for many years but the principal cause of the problem has been hard to find. In literature gait and force analysis have proven to be promising methods in linking claw injuries to surface material conditions. In present experiments the objective was to investigate if pig gait in different floor conditions can be characterised by a combination of kinematic and kinetic methods. To determine the relationship between claw disorder and floor physical properties, the factors controlling gait must be characterised. In the studies this was achieved by using kinematics and kinetics to record gait parameters and slip frequency. Kinematics were used to record gait parameters such as walking speed, stride length, swing and stance time, stride elevation together with limb support phases, gait symmetry, diagonality and duty factor. This was done by using two different types of digital video cameras with 25 Hz and 60 Hz frequency respectively. In both cases the film was imported, processed, and digitised in a commercial gait analysis programme. The kinetic method included a force plate which was used to record kinetic gait parameters such as stance time, vertical and horizontal forces, and time of peak vertical force. Ground reaction force (GRF) data were collected during the passage of moving pigs at 1 kHz. In the GRF data acquisition system the force plate was connected to a digital converter and a computer. The GRF was presented as three orthogonal components (longitudinal, latitudinal, and vertical force). The kinematic and kinetic methods proved to be reliable techniques for assessment of relevant gait parameters in characterising pig gait. The subject can be used as indicator in finding floor properties that better comply with the biological needs of the pig.

Keywords: Kinematics, Kinetics, Pig, Floor, Walk, Friction, Slip.

INTRODUCTION

Gait measurement methods

Subjective methods Subjective gait studies have been used in assessments of lameness in cattle (Manson and Leaver, 1988; Whay et al., 1997) and pigs (Main et al., 2000). The gait assessments are based on an observer's scoring system reflecting changes in gait leading to lameness. Lameness scoring can be a helpful tool in evaluation of the lameness disorder, but it does not provide sufficiently accurate measurements of gait (Flower et al., 2006). Although the gait scores can be compared, the accuracy of the scoring can be influenced by the observer's skill and perception (Whay et al., 1997; Main et al., 2000; Engel et al., 2003). Flower et al. (2005) reported that scoring systems had failed to relate to specific ailments up to then, and could fail in consistency between observers or even with the same observer if the scoring system was not validated.

Objective methods Objective methods such as kinetics and kinematics could avoid some drawbacks that the subjective grading methods have. Kinetics is the study of forces involved in motion (Hall, 1995). Kinetic studies in animals use force plate (FP), force shoes or pressure sensors to obtain ground reaction forces (GRF) from the animal limb. The GRF data provide information on vertical and horizontal forces exerted by the animal in different floor conditions, which can be used in assessing the forces used by the animal (Hottinger et al., 1996; Hodson et al., 2001; van der Tol et al., 2005; Thorup et al., 2007). Kinematics is the study of changes in position of body segments over time, without reference to the forces involved in motion (Hall, 1995). Small spheres as markers are commonly attached to the skin at standard anatomical locations, and high-speed cinematography or a digital video (DV) camera captures the movement of the animal. Video records are transferred to motion analysis software capable of digitising a sequence of movements automatically, and the data collected can provide information on the linear and angular displacements, velocity and accelerations of each marker (Barrey, 1999; Clayton and Schamhardt, 2001).

Kinematic gait analysis can be performed without repercussions on the subject as the measurements are made in the DV images, and the subject can be used as an indicator of normal gait, abnormal gait, overloading or slipping motion. The non-invasive technique that the DV camera offers also minimises animal (pig) handling, which is important since according to Main et al. (2000), the natural response of a pig to interference or provocation is a 'short fast advancement and then a steady pace or trot'.

Kinetic and kinematic analyses have been successfully used in studying gait and performance in horses (Drevemo et al., 1980; Merckens et al., 1988; Gustås et al., 2007) and dogs (Jayes and Alexander, 1978; Hottinger et al., 1996). Until recently, few kinematic or/and kinetic studies had been carried out in cattle (Herlin and Drevemo, 1997; Flower et al., 2005; van der Tol et al., 2005; Flower et al., 2006; Flower et al., 2007) and even fewer in pigs (Calabotta et al., 1982; Thorup et al., 2007).

Gait parameters Kinematic gait analysis allows basic gait parameters such as walking speed, stride length, stride speed, swing and stance phase to be determined (Barrey et al., 1999; Clayton and Schamhardt, 2001). Gait analysis was first based on a quantitative

analysis in the 1960s, when the distinctive properties of any symmetrical gait could be expressed as a point on a bivariate plot (Hildebrand, 1965; 1966).

Kinetic and kinematic pig studies Webb and Clark (1981a; 1981b) described measurements of walking pig claws in terms of GRF, but did not quantify any parameters. In studying the effect of dietary treatments on gait characteristics, Calabotta et al. (1982) used motion picture photography of pigs walking a treadmill to quantify measurements such as torso length, distance between hooks and pastern angle relative to horizontal, but no measurement related to gait performance.

Applegate et al. (1988) performed a kinematic study of 8 pigs (30-40 kg) in which the objective was to relate the number of slips of the pigs passing along a test aisle to floor properties and floor condition. A number of different concrete floors were tested, all wetted for one hour prior to testing. The floor friction was tested by a SRT friction device before and after pig passage along the test aisle.

Applegate et al. (1988) noted that stride length, walking speed, time and phase were influenced marginally and inconsistently by differences between wetted test surfaces, even though the range in surface friction was wide relative to commercial practice. However, hind limb stance time was 9% shorter than fore limb. The floor friction influenced the number of forward and backward slips significantly, and the fore limbs slipped more than the hind limbs. However, the forward slips observed were very small, in general less than 1 mm for pig fore and hind limbs.

The most comprehensive study yet of biomechanical gait analysis of pigs was performed by Thorup et al. (2007). The study involved both kinetic and kinematic analysis of pigs walking a straight test aisle with three concrete floor condition categories (dry, wet and greasy (rapeseed oil)). In all, 10 different pigs with a body weight of ~75 kg were used for each floor condition category. The pigs were found to adapt to the greasy floor conditions by lowering their walking speed (16%) and peak utilized coefficient of friction, UCOF. Furthermore the pigs reduced their stride length (7%) and increased their stance time (15%) in greasy conditions compared with dry floor conditions. The fore limbs differed from hind limbs biomechanically in receiving higher peak vertical forces, as well as higher mean vertical forces and longer stance time than the hind limbs.

EXPERIMENTAL SET-UP

Equipment In the present studies the test area consisted of two rectangular pens with a test aisle in between. The floor of the test aisle was covered by replaceable slabs. Pig gait on the test aisle was recorded by a built-in force plate (FP) level with the paved surface and a perpendicularly placed digital video (DV) camera. Temperature and humidity were recorded by a data logger during the test period.

In Study 1 the test aisle was a straight line (Figure 1), while in Study 2 the test aisle had a 30° curve just after the FP (Figure 2).

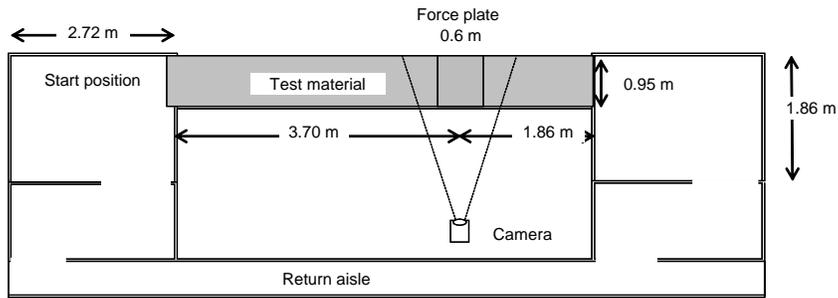


Figure 1. Plan of the test aisle used in Study 1 for pigs walking a straight line.

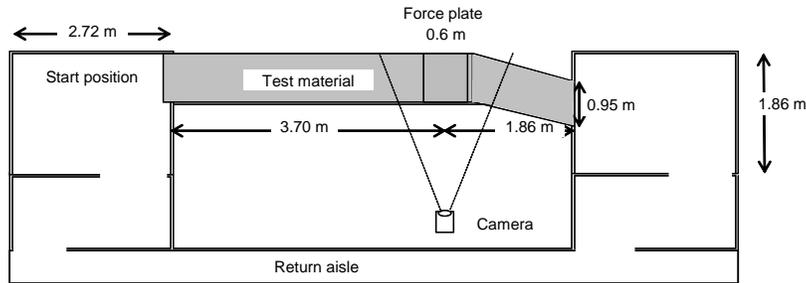


Figure 2. Plan of the test aisle used in Study 2 for pigs walking a curve.

In Study 1, DV data were collected at 25 Hz, VGA quality with 640 x 480 pixels of the moving pigs, which captured 1.3-1.5 m of a pig body length (average 1.4 m) in the camera viewer. In Study 2, DV data were collected at 60 Hz by an IEEE 1394 camera with 656 x 490 pixels in 2.3 m of the test aisle.

The camera was spatially calibrated using a rectangle of known dimensions placed in the central path of the test aisle before each replicate. After the experiment each film was imported and processed in a gait analysis programme (Vicon, Peak Motus 9.0, UK) in which the films were cut and digitised. Five positions of the animal were digitised in each DV frame: the four claw tip positions and either nose tip or tail root position. The nose tip/tail root position of the animal was used to calculate the walking speed and the claw tip positions were used in determining stride parameters such as stride length, stride time, stride speed, swing time, stance time, and stride elevation together with limb support phases, gait symmetry, diagonality, and duty factor. The stride parameters and their definitions are described by von Wachenfelt et al. (2008).

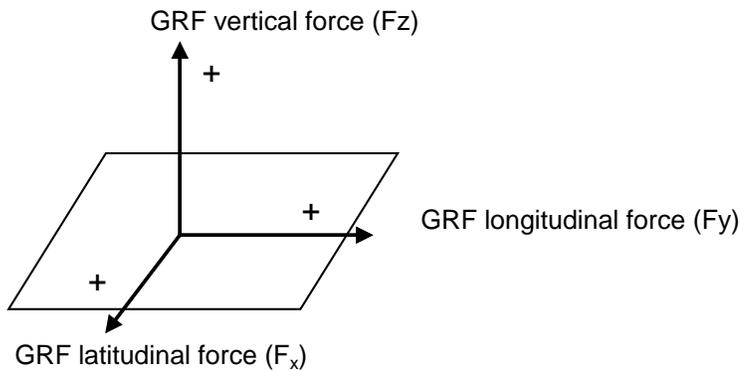


Figure 3. The force plate coordinate system, with force directions shown as reaction oriented forces.

GRF data were collected during the passage of the moving pigs at 1 kHz using an FP. The test aisle and the FP were covered with the same concrete or rubber mat flooring material. The GRF data acquisition system consisted of an FP (Bertec Corporation, Ohio, USA), connected to a digital converter and a computer. Three GRFs (GRF_v and the horizontal components GRF_{long} and GRF_{lat}) were recorded by the FP (Figure 3).

Data processing Two dimensional (2D) coordinates were constructed by direct linear transformation in the gait analysis programme, from which 2D velocity and 2D coordinates were imported into an Excel spreadsheet for further processing.

The kinetic data were obtained by sampling the GRF data in 300 evenly distributed values during the stance phase. The 300 values corresponded to the mean stance phase length. Sampling was performed in three force directions using the vertical force curve as a template. All GRF data were normalised to pig body weight.

A mean value per pig and type of surface conditions was compiled for each of the 300 sampling points and overall mean and peak value were calculated for 10 pigs per floor condition type.

The claw force data were processed to determine the ratio of horizontal to normal forces, i.e. Utilized Coefficient Of Friction (UCOF), which was calculated as a mean of peak UCOF during stance time for 10 pigs per floor condition. The UCOF data were screened for spurious values and values less than 10% of the peak vertical force were discarded. These originated from small vertical force values during claw-on and claw-off. Because of division by small numbers in the UCOF ratio, these UCOF values showed false maxima (Cham and Redfern, 2002a, 2002b; Powers et al., 2002).

RESULTS

Kinematics Gait differences due to floor conditions could be registered (von Wachenfelt et al. 2008, 2009a, 2009b). Examples of results from measurements are presented in Table 1.

Kinetics Mean vertical and horizontal force curves exerted by fore and hind limbs on the FP from 10 pigs walking a straight line on concrete are illustrated in Figure 4. Generally the vertical force showed two local maxima with a minimum in between. The

longitudinal horizontal force roughly described a sinusoidal curve, with a negative maximum illustrating backward forces acting on the claw followed by a positive maximum with

Table 1. Kinematic parameters from the floor conditions and limbs in Study 1. Comparison between fore- and hind limbs and between clean and fouled concrete floor conditions (10 readings per pig and floor condition, mean and standard deviation (SD)).

Parameter	Conditions		p ¹	Limb		p ¹
	Clean	Fouled		Fore	Hind	
Walking speed, m/s	1.65	1.38	*			
	(0.13)	(0.19)	*			
			*			
Stride length, m	0.86	0.72	*			
	(0.11)	(0.12)	*			
			*			
Swing/stance phase ratio	0.90	0.84	ns	0.81	0.93	*
	(0.09)	(0.14)		(0.10)	(0.11)	*
						*
Stance time, s	0.27	0.32	*	0.31	0.28	*
	(0.02)	(0.04)	*	(0.05)	(0.05)	

1) Probability limits for statistical significance: ns = non-significant; * = p<0.05; ** = p<0.01; *** = p<0.001

Forward forces acting on the claw The lateral horizontal force was less consistent and varied between fore- and hind limbs, but was mainly negative during the stance phase, which meant that the claw had an outward thrust in the lateral direction.

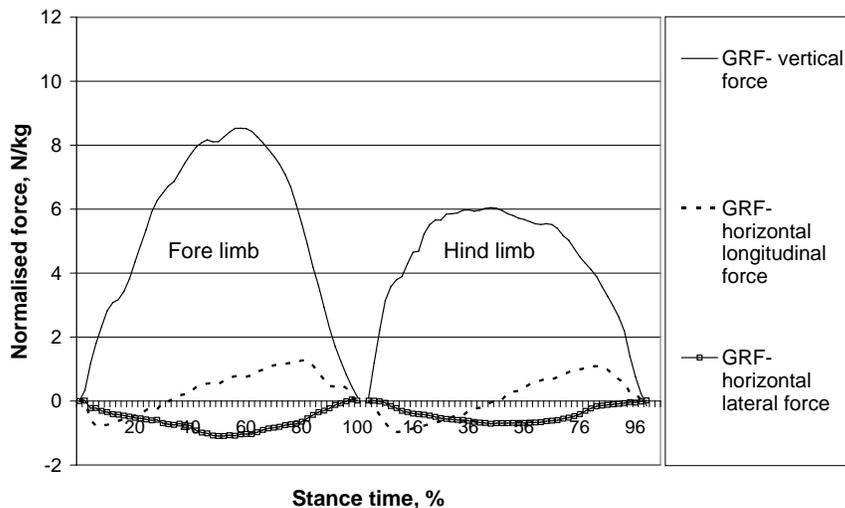


Figure 4. Normalised GRF exerted by fore and hind limbs during stance phase from 10 pigs walking a straight line. Values derived from force plate measurements on clean concrete.

DISCUSSION The accuracy of a force plate analysis is largely determined by the subject's walking speed and associated stride length and stance time (Khumsap et al.,

2002). McLaughlin et al. (1996) concluded that all variation in subject velocity should be minimised in performing force plate analysis in horses. In dogs, the recommended variation should be less than 0.6 m/s at the walk (Roush and McLaughlin, 1994; Tano et al., 1998). In laboratory measurements on humans, self-chosen gait speeds have ranged from 0.97 to 1.51 m/s (Redfern et al., 2001; Abel et al., 2002). The standard deviations of GRF forces in the present studies were somewhat higher but of same order of magnitude as those in other studies (Hodson et al., 2001; van der Tol et al., 2005; Thorup et al., 2007).

CONCLUSION Kinematic and kinetic methods proved to be reliable techniques for assessment of relevant gait parameters in characterising pig gait, using the subject as indicator in finding floor properties that better comply with the biological needs of the pig.

The quantitative non-invasive measurement technology used in the studies is a useful tool but can probably only be used in laboratory experiments. Even so, it could provide validation data for instruments used in practice, e.g. a friction measurement device. This would allow the results to be applied at farm level.

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