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GAIT AND FORCE ANALYSIS OF PROVOKED PIG GAIT ON CLEAN AND FOULED RUBBER MAT SURFACE

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ABSTRACT Materials that increase floor friction forces in absorption of foot pressure could reduce the risk of slipping, i.e. promote walking safety. The effects of fouled rubber mat floor conditions on the gait of 10 pigs walking in a curve, using kinematics and kinetics to record gait parameters and slip frequency are described and compared with clean conditions. Pigs adapted to fouled floor condition through reduced walking speed (10%), prolonged swing and stance time and a higher number of 3-limb support phases, but kept stride length and diagonal constant. This adaptation produced a threefold reduction in lateral horizontal forces and kept breaking and propulsion forces constant, resulting in a constant peak utilised coefficient of friction (UCOF) level in fore limbs but a 31% reduction in UCOF in hind limbs. The better traction for pigs walking on rubber matting compared with concrete is due to a more effective transmission of forces from the limb to the elastomer, dissipating the forces into energy within the material, and thus impeding the effect of centripetal force, with less displacement of the body's centre of gravity and less forward and backward slip. Pig forward slip frequency on fouled rubber matting was 65 and 51% lower for fore and hind limbs respectively compared with pigs walking a curve on fouled concrete. The soft flooring material improved gait adaption and could thus improve walking safety.

Keywords: pig, floor, friction, slip, rubber mat, kinematics, kinetics.

INTRODUCTION For reasons of technical design and economy, flooring and flooring systems in animal houses are often made from hard materials, which mean that they do not deform under the pressure of an animal foot. In contrast, pasture ground is deformable by foot pressure (Hernandez-Mendo et al., 2007). Recent studies of rubber walkways in cubicle barns have confirmed the benefits for cow locomotion (Boyle et al., 2007; Flower et al., 2007; Telezhenko et al., 2007; Reubold, 2008). Reubold (2008) showed in a study of six different rubber walkway covers that a deformation of 1.4 mm gave good slip resistance and reduced claw lesions. Studies on foot and leg injuries in pig husbandry systems (Jørgensen 2003; Lahrmann et al., 2003) have focused on identifying the cause of the problem. Gait and force analysis has proven to be a useful method in linking claw injuries to surface material conditions (Applegate et al., 1988; Flower et al., 2005; van der Tol et al., 2005; Thorup et al., 2007; von Wachenfelt et al., 2008). Floor properties such as surface coefficient of friction (COF), abrasiveness and softness (Webb & Nilsson, 1983; Nilsson, 1988), and their interactions with the pig claw (Webb & Nilsson, 1983; Webb, 1984; Applegate et al., 1988; Thorup et al., 2007) are among the key factors in understanding the causes of slip and fall accidents (Redfern & DiPasquale, 1997; Hanson et al., 1999). The foot forces that are generated when a foot comes in contact with the ground require friction to prevent slip (Hanson et al., 1999). In pig gait, the COF depends on claw properties, flooring and floor conditions (e.g. dry, wet or manure-fouled). A material that increases floor friction forces at toe-on and toe-off in absorption of foot pressure could reduce the horizontal forces at impact and thereby also reduce the risk of slipping, i.e. increase walking safety (Nilsson, 1988; van der Tol et al., 2005). The objectives of the present study were to characterise provoked pig gait (walking a curve) on a clean rubber mat surface and to evaluate the effect of surface fouling on pig gait by use of kinematics and kinetics. A previous study showed that on hard flooring, pigs adapted to the floor surface but had a high slip frequency in fouled floor condition (von Wachenfelt et al., 2009b). The hypothesis of the present study was that pigs would adapt their gait to the softer floor when walking a curve, and that the softer flooring would improve walking safety compared with hard flooring materials.

MATERIALS AND METHODS

Animals Ten Swedish Landrace pigs were used in the study. Before and after the test, the claws were examined according to a standard procedure (Brooks et al., 1977). The average animal weight during the test period (4 d) was 98 kg (SD = 18 kg).

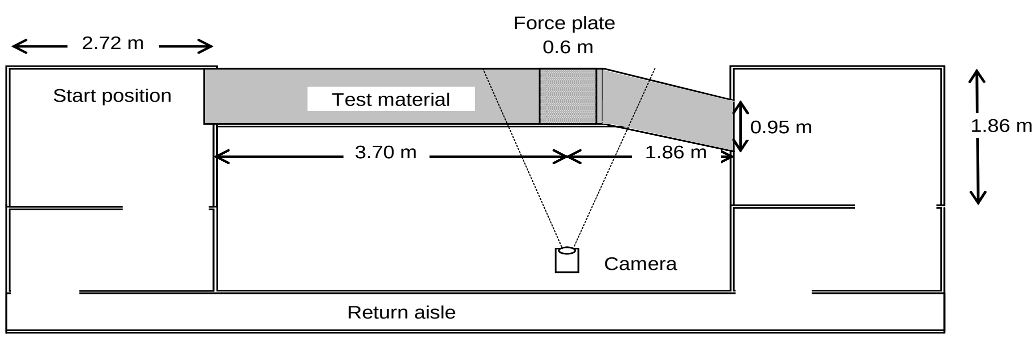


Fig. 1. Plan of the test area

Experimental set-up A test aisle was built with a 30° right-hand curve placed immediately after a force place (Fig. 1). The test aisle was covered by 20 mm thick rubber matting (KEN® Gummiwek Kraiburg Elastik, Germany). Pig gait on the test aisle was recorded by a built-in force plate (FP) and a perpendicularly placed digital video (DV) camera. Two floor conditions were tested, clean and artificially fouled by pig faeces, as described in von Wachenfelt et al. (2008). The DV data were collected at 60 Hz and FP data sampled at 1 kHz.

Experiment The pigs walked the test aisle individually at a self-determined speed. The number of passages for each pig was 10 per replicate. Two replicates were conducted for each floor condition, the experiment described in more detail by Nilsson et al. (2010). Two friction test devices, a horizontal pull slip meter (PSM) and a dynamic pendulum impact-type tester (SRT) (ASTM, 1993) were used to record coefficient of friction (COF) and British Pendulum Number (BPN) of the flooring (von Wachenfelt et al., 2009a).

Data processing The definition and processing of stride, force and friction data were conducted as described by von Wachenfelt et al. (2008, 2009a). The precondition for stride data calculation was a full stride (which includes a stance phase when the limb is in contact with the ground and a swing phase when the limb is not in contact with the ground (Clayton, 1997)) from each passage. Each stride and GRF parameter was calculated as an average per pig and floor condition and for both front and hind limbs. The statistical basis for the calculation was the average of 10 pigs per floor condition. Slip frequency was defined as the number of slips in relation to the total number of stances per pig and limb. The number of slips, slip length and slip time were recorded from DV data based on a complete stride for each passage and all limbs. The slips were divided into forward and backward slips. A slip below a threshold of 10 mm was referred to as micro-slip and disregarded, whereas a slip above 10 mm was characterised as a slip from which the subject recovered or did not recover from (Applegate et al., 1988; Cham & Redfern, 2002b). No slips occurred from which the pigs fell and did not recover, i.e. could not continue the walk.

Statistics Paired t-testing was used to compare differences within and between material conditions and to examine differences between fore and hind feet within stride, force and friction data, and walking a curve. The data were tested for normal distribution. The probability limits for evaluating statistical significance were: * = $p<0.05$; ** = $p<0.01$; *** = $p<0.001$. The results are presented as mean and standard deviation (SD).

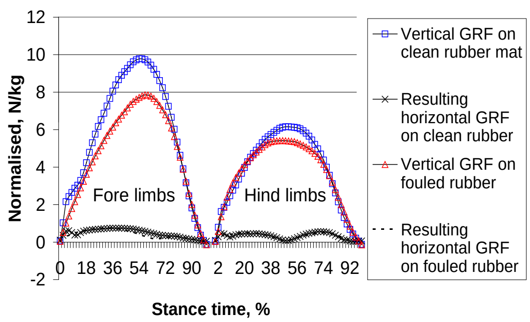
RESULTS

Gait differences due to surface conditions in walking in a curve All data were normally distributed. With a curve walking speed of 1.18 m/s in clean floor conditions and 1.06 m/s in fouled floor conditions, the walk of *pigs walking a curve on rubber mat flooring* (CWr) was characterised by a four-beat symmetrical gait distinguished by alternating 2- or 3-limb support phases. Single or 4-limb support phases comprised less than 7 and 1% of observations, respectively. The number of 2-limb support phases decreased from 81 to 70% in fouled floor conditions compared with clean, while the diagonality remained constant and the number of 3-limb support phases increased from 11 to 23%. For pigs in fouled floor conditions compared with clean, swing and stance time increased by 10% and number of 3-limb support by two-fold (Table 1). Vertical and resultant horizontal GRF's for fore and hind limbs from the mean of 10 curve walking pigs on clean and fouled concrete are illustrated in Figure 3a. The mean and peak GRF_v applied decreased by 10 and 20% for fore and hind limbs, respectively, in fouled floor condition, while time of peak vertical force for fore limbs occurred 8% later than mid-stance (half-stance time) compared with 6% for clean conditions. The hind limbs used mid-stance for full vertical force in clean floor conditions, but in fouled floor conditions the hind limbs applied full force 5% earlier than mid-stance (Table 2). The minimum GRF_{long} (braking force) and the peak GRF_{long} (propulsion force) were constant in both limbs and both floor conditions. The minimum GRF_{lat} (outward correction force) showed a significant reduction for fore (52%) and hind (46%) limbs in fouled floor conditions compared with clean, together with a 50% reduction in peak GRF_{lat} (inward correction force) for fore limbs and a 24% reduction in peak UCOF for hind limbs in fouled floor conditions (Figure 3b).

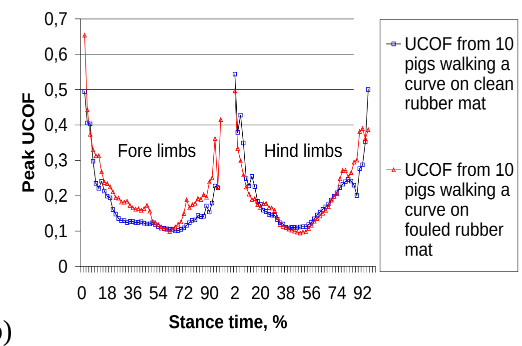
Table 1. Stride characteristics of 10 provoked pigs walking a curve in clean and fouled rubber floor conditions. Comparison between fore and hind limbs and between conditions (number of samples (n), mean and standard deviation (SD))

Parameter	Conditions					Limb[2]				
		Clean		Fouled			Fore		Hind	
	n	Mean (SD)	n	Mean (SD)	p[1]	n	Mean (SD)	n	Mean (SD)	p[1]
Walking speed, ms^{-1}	467	1.18 (0.14)	475	1.06 (0.11)	*					
Stride length, m	467	0.94 (0.08)	475	0.92 (0.06)	ns					
Stride time, s	467	0.82 (0.08)	475	0.88 (0.06)	*					
Stride speed, ms^{-1}	467	1.19 (0.11)	475	1.07 (0.10)	*					
Swing time, s	467	0.40 (0.02)	475	0.44 (0.03)	***					
Swing/stance time ratio	476	0.97 (0.12)	468	0.99 (0.10)	ns	472	1.01 (0.09)	472	0.95 (0.12)	*
Stance time, s	467	0.41 (0.05)	475	0.45 (0.05)	*	472	0.43 (0.05)	472	0.44 (0.06)	*
Max stride elevation, m	472	0.06 (0.01)	456	0.07 (0.02)	ns	464	0.07 (0.02)	464	0.06 (0.01)	ns
No. of 1-limb sup. phases	118	7.23 (2.60)	114	7.24 (2.26)	ns					
No. of 2-limb sup. phases	118	80.74 (4.96)	114	69.99 (5.67)	**					
No. of 3-limb sup. phases	118	11.29 (6.20)	114	22.51 (6.81)	**					
No. of 4-limb sup. phases	118	0.03 (0.11)	114	1.05 (1.64)	ns					
Symmetry, %	118	51.18 (1.06)	114	50.37 (1.27)	ns					
Diagonality, %	118	89.89 (3.93)	114	88.67 (3.64)	ns					
Duty factor, %	467	50.75 (0.03)	475	50.17 (0.02)	ns					

1) Probability limits for evaluating statistical significance: ns= non significant; * = $p<0.05$; ** = $p<0.01$; *** = $p<0.001$
2) Fore and hind limbs in clean and fouled conditions



a)



b)

Figure 3a. Vertical and resultant horizontal GRF's for fore and hind limbs from the mean of 10 pigs walking in a curve on clean and fouled rubber mat. Figure 3b Peak UCOF values for fore and hind limbs from the mean of 10 pigs walking in a curve on clean and fouled rubber mat. Values at the very start and end of the stance phase were discarded to avoid 'instability' regions when both shear and normal forces approach zero.

Gait difference between fore and hind limbs in walking in a curve Pig fore limbs showed significantly higher swing/stance time ratio and lower stance time than hind limbs but consistent maximum stride elevation in the two types of floor conditions (Table 1). The mean and peak GRFv applied were 39 and 50% higher for fore limbs than for hind limbs, respectively, in both floor conditions, while the time of peak GRFv during stance occurred earlier for hind limbs than for fore limbs in both floor conditions (Table 2). The peak GRFlong was 43 and 63% lower for fore limbs than for hind limbs in clean and fouled floor conditions, respectively. In fouled floor conditions the peak GRFlat of fore limbs was double that of hind limbs. In clean floor conditions, fore limbs utilised 26%

more minimum GRFlong than hind limbs, whereas in fouled floor condition this difference in braking force increased to 39%. The minimum GRFlat applied by fore limbs was 1.9-fold and 1.7-fold higher than that of hind limbs in clean and fouled floor conditions, respectively. Regarding peak UCOF, the fore limbs utilised 21% less than hind limbs in clean floor conditions, but there was no difference between fore and hind limbs in fouled floor conditions.

Table 2. Force characteristics of 10 provoked pigs walking a curve in clean and fouled rubber floor conditions. Comparison between fore (F) and hind (H) limbs and between material conditions (number of samples (n), mean and standard deviation (SD))

Parameter	Limb	Floor conditions						
		Clean			Fouled			
		n	Mean (SD)	p[2]	n	Mean (SD)	p[2]	p[3]
Mean GRF_v (Nkg^{-1})[1]	F	138	5.83 (0.36)	***	149	4.79 (0.46)	***	***
	H	136	3.90 (0.33)		172	3.71 (0.26)		ns
Peak GRF_v (Nkg^{-1})[1]	F	138	9.84 (0.71)	***	149	7.91 (0.99)	***	***
	H	136	6.26 (0.85)		172	5.52 (0.58)		*
Timing of peak GRF_v (s)	F	138	0.15 (0.03)	*	149	0.21 (0.04)	***	***
	H	136	0.14 (0.02)		172	0.15 (0.03)		ns
Peak GRF_{long} (Nkg^{-1})[1]	F	138	0.26 (0.13)	***	149	0.33 (0.14)	***	ns
	H	136	0.60 (0.17)		172	0.52 (0.12)		ns
Min GRF_{long} (Nkg^{-1})[1]	F	138	-0.72 (0.09)	***	149	-0.79 (0.13)	***	ns
	H	136	-0.57 (0.11)		172	-0.57 (0.06)		ns
Peak GRF_{lat} (Nkg^{-1})[1]	F	138	0.12 (0.03)	***	149	0.06 (0.03)	ns	***
	H	136	0.06 (0.04)		172	0.06 (0.04)		ns
Min GRF_{lat} (Nkg^{-1})[1]	F	138	-0.46 (0.19)	**	149	-0.22 (0.12)	*	**
	H	136	-0.24 (0.07)		172	-0.13 (0.03)		***
Peak UCOF	F	138	0.46 (0.11)	*	149	0.55 (0.20)	ns	ns
	H	136	0.58 (0.10)		172	0.44 (0.12)		**

1) Normalised to body weight
2) Significance level comparing fore and hind limbs: * = p<0.05; ** = p<0.01; *** = p<0.001; ns= non significant
3) Significance level comparing material conditions

Table 3. Coefficients of static friction (SCOF), dynamic friction (DCOF) and skid resistance (BPN) for rubber floorings tested in laboratory and pig house experiments (PSM: n = 10, SRT: n = 15)

Test method	SCOF[3]		DCOF[3]		BPN[4]		Temperature °C; Relative humidity %
	Mean (SD)	p[5]	Mean (SD)	p[5]	Mean (SD)	p[5]	Mean
Clean							
PSM-leather[1]	1.01 (0.02)	***	0.96 (0.01)	***			19.4 ± 0.2; 32
SRT-leather[2]					64.1 (0.03)	***	16.7 ± 3.3; 54
SRT-rubber					90.3 (0.03)	***	20.4 ± 0.4; 67
Fouled							
PSM-leather	0.65 (0.04)		0.53 (0.03)				19.4 ± 0.2; 32
SRT-leather					44.1 (0.05)		16.7 ± 3.3; 54
SRT-rubber					50.5 (0.05)		20.4 ± 0.4; 67

1) PSM-leather = pull slip meter with leather test body
2) SRT-leather = dynamic pendulum impact-type tester with leather test body
3) Laboratory experiment
4) Pig house experiment
5) Significance level comparing material conditions: * = p<0.05; ** = p<0.01; *** = p<0.001; ns= non significant

Floor friction and slip Significant differences in SCOF and DCOF were found between clean and fouled floor conditions for PSM-leather, and for both SRT-leather and SRT-rubber (Table 3). In general, backward slip time, length and frequency were higher for hind limbs and forward slip time and frequency were higher for fore limbs. Backward and forward slip lengths were of the same order of magnitude. However, compared with forward slip frequency, backward slip frequency was 36% lower for fore limbs and 63% higher for hind limbs (Figure 5, Table 4). In clean floor conditions no slips > 10 mm were observed.

Table 4. Slip characteristics (> 10mm) of 10 provoked pigs walking in fouled floor conditions. Comparison between fore (F) and hind (H) limbs and between walking a curve on concrete and rubber matting (number of readings (n), mean and standard deviation (SD))

Parameter	Walking a curve on fouled concrete[2]				Walking a curve on fouled rubber			
	n	Limb	Mean (SD)	p[1]	n	Mean (SD)	p[1]	p[1]
Backward slip time, s	234	F	0.06 (0.05)	**	238	0.03 (0.03)	**	*
	234	H	0.14 (0.06)		238	0.08 (0.07)		***
Backward slip length, m	234	F	-0.02 (0.01)	*	238	-0.02 (0.01)	***	ns
	234	H	-0.04 (0.03)		238	-0.03 (0.02)		ns
Backward slip frequency, %	234	F	30.01 (18.80)	***	238	31.83 (14.84)	**	ns
	234	H	45.21 (19.85)		238	46.72 (20.01)		ns
Forward slip time, s	234	F	0.22 (0.09)	***	238	0.18 (0.07)	*	*
	234	H	0.15 (0.09)		238	0.12 (0.09)		ns
Forward slip length, m	234	F	0.09 (0.05)	*	238	0.09 (0.05)	ns	ns
	234	H	0.05 (0.05)		238	0.06 (0.06)		ns
Forward slip frequency, %	234	F	82.14 (25.86)	***	238	49.84 (20.74)	***	**
	234	H	43.09 (17.83)		238	28.63 (16.80)		**

1) Probability limits for evaluating statistical significance: ns= non significant; * = p<0.05; ** = p<0.01; *** = p<0.001
2) Data published in von Wachenfelt et al., 2009b

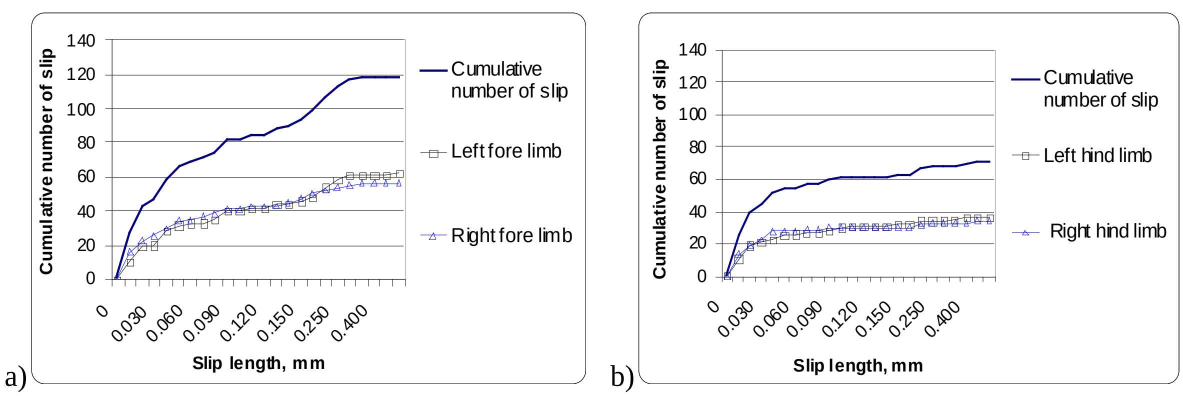


Figure 5. Number of slips for 10 pigs walking a curve (30° to the right) in fouled rubber floor conditions, a) fore limbs, 118 slips >10 mm in 238 passages on the test aisle, b) hind limbs, 70 slips > 10 mm in 238 passages on the test aisle.

DISCUSSION

Kinematics

Gait differences due to floor conditions The symmetrical walking pattern with alternating 2- and 3-limb support phases exhibited by the pigs in the present study was similar to that reported for pigs (Thorup et al., 2007; von Wachenfelt et al., 2008). In clean floor condition the CWr pigs applied a moderate walking pattern with lower walking speed (1.18 m/s), longer swing and stance time compared with straight walking pigs (von Wachenfelt et al., 2008) in both floor conditions. The CWr pigs adapted to fouled floor condition through reduced walking speed (10%), lower number of 2-limb and higher number of 3-limb support phases, longer swing and stance time and prolonged stance time for hind limbs. In their gait adaption to fouled floor condition, CWr pigs differed significantly from *curve walking pigs on concrete* (CWc) (von Wachenfelt et al., 2009b) in higher stride length and diagonality but lower duty factor.

Gait differences between fore and hind limbs Both CWr and CWc pigs (von Wachenfelt et al., 2009b) prolonged their hind stance phase compared with pigs walking a line (Applegate et al., 1988; Thorup et al., 2007; von Wachenfelt et al., 2009a), probably to increase stability as the hind limb is closer to the body's centre of gravity (Applegate et al., 1988).

Kinetics The main effort of CWc pigs in previous studies (von Wachenfelt et al., 2009b) was to reduce horizontal but also vertical forces in their gait adaption to fouled floor condition, and this was also observed in this study for the CWr pigs.

Gait differences due to floor condition and between fore and hind limbs High mean and peak GRF_v were observed for fore limbs in both CWr and CWc pigs (von Wachenfelt et al., 2009b) compared with hind limbs in both clean and fouled floor conditions. In adapting to fouled floor condition, CWc pigs reduced their fore limb mean and peak GRF_v by 13 and 16% respectively, but the mean and peak GRF_v reduction by CWr pigs was still 5% more. In hind limbs of both CWr and CWc pigs, vertical forces were more consistent between floor conditions, although the CWr pigs increased their peak GRF_v by 8% in clean floor condition compared with CWc pigs, which shows that CWr pigs had better gait control walking the curve. Compared with CWc pigs (von Wachenfelt et al., 2009b), the CWr pigs used 6 and 19% more braking force in fore and hind limbs respectively in clean floor condition, but 44 and 28% less in fore and hind limbs, respectively, in fouled floor condition (Table 2). The use of braking forces by CWr pigs in both limbs and floor conditions was significantly different from that of CWc pigs and the shorter stance time in both floor conditions indicates that the CWr pigs had a firmer foot grip on the floor surface. The CWr pig fore limb braking force values in both clean and fouled floor conditions were consistent with values reported for straight walking pigs on concrete (Thorup et al., 2007) further implying that CWr pigs had a firm foot grip. The 94% higher propulsion force in CWr pig fore limbs in fouled floor condition revealed better traction compared with CWc pigs and the propulsion values corresponded to findings in straight walking pigs (von Wachenfelt et al., 2008). The peak and minimum GRF_{lat} indicate that CWr pigs did not choose to restrict the lateral stabilising forces in order to maintain stability in either of the floor conditions. In fact CWr pigs increased the peak GRF_{lat} for the hind limbs three-fold in fouled condition compared with CWc pigs (von Wachenfelt et al., 2009b).

Utilised cofficient of friction The gait adaption of the CWr pigs is clearly shown in Figure 3a, where the GRFv decreases while the resulting horizontal force is mainly consistent during stance phase for both limbs in fouled floor conditions compared to clean. In order to reduce impact at toe-on, the pigs also delayed the timing of peak GRFv, especially for fore limbs in fouled condition, as shown in previous study (von Wachenfelt et al., 2009). van der Tol et al. (2005) compared GRF and UCOF values for fore and hind limbs of cows walking in a straight line and walking in a curve and related this to the stance time corresponding to Figure 3a and 3b. The straight line GRFv showed two local maxima with a minimum in between, but for cows walking in a curve the GRFv maxima and the minima were not as evident, which corresponds with the GRFv for CWr pigs in the present study. The resulting horizontal GRF of fore limb of the curve walking cows (van der Tol et al., 2005) had a higher amplitude at 20% of stance phase and a similar high amplitude at 85% of stance phase compared to cows walking straight. A corresponding amplitude increase was not found in CWr pigs at corresponding 20 and 85% of stance phase in Fig 3a. The lower walking speed on fouled flooring can contribute to a reduction in UCOF values as reported by Cham & Redfern (2002a) and Powers et al. (2002). When comparing UCOF during different walking tasks for humans, Burnfield et al. (2005) found that healthy adults aged 20 to 40 years had an mean peak UCOF of 0.48 when negotiating a 90° turn, while the mean peak UCOF of level walking was 0.23 in clean floor conditions. However van der Tol et al. (2005) found that UCOF for cows walking a 90° curve (FP placed in the middle of the curve) in dry floor condition remained 0.40 for almost the entire stance phase and the highest recorded UCOF was 0.80 during the heel strike phase during stopping tests. In the current study the FP was placed just before the curve, registering the moment of curve adaption, which could explain the high CWr peak UCOF level during the stance phase but also the high peak UCOF level at toe-on and toe-off compared with straight walking pigs (Thorup et al., 2007; von Wachenfelt et al., 2009a). For the CWr pigs the better floor friction probably increased the floor traction and impeded the horizontal forces at impact, creating the possibility of an appropriate but smaller gait adaption (no stride length or diagonality reduction).

<u>Floor friction and slip</u> Forward slip frequency for CWr and CWc pig fore limbs was higher than the backward slip frequency, in agreement with Applegate et al. (1988). However, in CWr pig hind limbs there were less forward slip than backward slip. For the rubber mat flooring, forward slip frequency was reduced by 65 and 51% for fore and hind limbs, respectively, compared with concrete. The cumulative frequency of slips for CWr pigs showed less difference between left and right limbs compared with CWc pigs, which could be the result of firmer foot grip (Figure 3a). In CWr and CWc fouled floor condition, the PSM SCOF and SRT values for the original rubber test body were constant, but the corresponding value for the leather test body in fouled floor condition in the present study (approx. 44 BPN) was higher than for CWc flooring but considerably lower than in the Applegate et al. (1988) study. The difference in CWr and CWc pig (von Wachenfelt et al., 2009b) slip frequency could perhaps have an explanation in lower DCOF value for the fouled concrete, but considering the major stride and force differences between CWr and CWc pigs the explanation is more likely to lie in deformation of the flooring material, which could provide additional friction by enabling the foot to sink into the floor and generate more traction (Nilsson, 1988; Reubold, 2008).

<u>Gait adaption</u> The strategies employed by pigs to avoid slipping and falling are very much the same as those employed by humans (Cham & Redfern, 2002a), where a significant reduction in peak UCOF occurs when the subject anticipates slippery surfaces and attempted posture control. In pigs this includes more 3-feet support phases and in CWc pigs (von Wachenfelt et al., 2009b) lowered diagonality. Walking pigs in clean

floor condition utilise the frictional property of floors to a greater extent than humans, but slightly less than cows (Thorup et al., 2007; von Wachenfelt et al., 2009a). The moderate curve design in this study revealed that pigs adapted to fouled floor condition but also that the flooring material can improve gait adaption and thus improve walking safety.

CONCLUSION Provoked pigs walking in a curved test aisle on rubber matting use a symmetrical walking pattern with alternating 2- and 3-limb support phases. Pigs walking a curve in clean rubber floor condition have a cautious but confident walk. The pigs utilise 26% more braking force on the fore limbs than on the hind limbs, which increases to 39% in fouled floor conditions. In clean floor conditions rubber mat pigs use 6 and 19% more braking force in fore and hind limbs respectively, but in fouled floor condition 44 and 28% less in fore and hind limbs, respectively, compared with pigs walking in a curve on concrete. Pigs walking on rubber matting adapt to fouled floor condition through reduced walking speed, prolonged swing and stance time and a higher number of 3-limb support phases, but keep stride length and diagonality constant. Pig adaption in fouled floor condition comprises a threefold reduction in lateral horizontal forces, but constant braking and propulsion forces, which results in a consistent peak UCOF level in fore limbs and a 31% reduction in hind limbs in fouled floor condition. The basis of better traction for pigs walking on rubber matting compared with concrete are due to a more effective transmission of forces from the limb to the elastomer, dissipating the forces into energy within the material, and thus impeding the effect of centripetal force, with less displacement of body centre of gravity and less forward and backward slip. Forward slip frequency of pigs on rubber matting is 65 and 51% lower for fore and hind limbs respectively compared with pigs walking in a curve on concrete. The moderate curve design showed that pigs adapt to fouled floor condition but also that the flooring material can improve gait adaption and improve walking safety.

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