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Repeated locomotion scoring of a sow herd to measure lameness: consistency over time, the effect of sow characteristics and inter-observer reliability

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Abstract

Investigating variability of scores between different observers, between animals and over time aids the design of valid sampling methodologies for measuring animal welfare. Locomotion scores (0 to 5 scale) were collected: i) from 154 sows in one herd, using three to five observers each time, and scoring sows on up to ten occasions over a 19-month period; and ii) for 123 of these sows, locomotion scoring also took place prior to farrowing and at weaning. The distribution of scores was highly skewed towards low scores (0: 84.8%, 1: 9.5%, 2: 4.0%, 3+: 1.7%). Sows showed moderate consistency in their scores over time and later parity sows had higher scores, but there was no effect of stage in the reproductive cycle (days pregnant, pre-farrowing, post-weaning). This suggests that infrequent visits to a farm (eg annual) might provide an accurate estimate of the extent of lameness if a representative range of parities was sampled, although a larger study of more farms would be required to investigate this. The three different types of agreement between observers (absolute differences, matching and association) were assessed as follows: i) analysis of absolute differences between observers showed that the farm manager scored lower than researchers/technicians; ii) exact matching approaches suggested fair or good agreement — agreement was poorest for mild gait abnormalities (score 1 'stiff'), and agreement improved if scores were combined into 'sound' (0–1) and 'lame' (2–5) categories; and iii) measures of association suggested moderate agreement. Inter-observer reliability improved over time until the 5th scoring event. To improve inter-observer agreement, observer training/practice and the use of fewer categories are recommended, and inter-observer agreement should be checked regularly.

Keywords: *animal welfare, inter-observer agreement, lameness, locomotion scoring, pigs, sows*

Introduction

On-farm measurement of animal health and welfare is an important and current issue, to meet consumers' demands for demonstrably high standards of farm animal welfare (Blokhuis *et al* 2003, 2008). Setting standards and inspecting to ensure that they are met is a goal of government agencies (Gibbens 2008) and of voluntary farm assurance schemes such as the UK Red Tractor scheme, free range, ecological and organic (Main *et al* 2003, 2007; Veissier *et al* 2008). Membership of such schemes depends generally on the producer meeting certain 'design criteria' (Rushen & de Passillé 1992) relating to the housing and resources provided to animals (such as stocking density, drinkers, substrates), management (eg weaning age in pigs, age at slaughter) and administration (eg keeping accurate records of the use of drugs). Conformance with these criteria is generally assessed in a visit which takes place approximately once a year and takes less than a day to complete (Main *et al* 2007).

With a few exceptions, direct assessment of health and welfare by inspecting the animals themselves (animal-based or 'performance criteria'; Rushen & de Passillé 1992) has not formed part of these schemes. Recently, an EU-funded project 'Welfare Quality®' (Blokhuis *et al* 2003) developed a comprehensive animal-based scoring system for on-farm assessment of animal health and welfare for pigs (Welfare Quality® 2009) and other housed species. The measures adopted were assessed for validity (does the indicator really measure what it should), repeatability (across observers), and feasibility (can it be assessed quickly enough to be included in a short visit). This process has been described in general terms but not in detail (Keeling *et al* 2009; Knierim & Winckler 2009).

Integration of multiple measures into an overall assessment is a difficult part of Welfare Quality® (Botreau *et al* 2007a,b,c, 2009; Knierim & Winckler 2009) and of similar schemes (eg Main *et al* 2007). Even prior to reaching this stage, though, there are a number of difficulties (Knierim & Winckler 2009). For any single measure, there are already practical constraints: on-farm scoring of animal welfare involves a sampled subset of animals from each age class and housing type, often by one trained observer in an annual visit of less than one day (Mullan *et al* 2009). Some researchers have attempted to assess the effect of such low

Figure 1

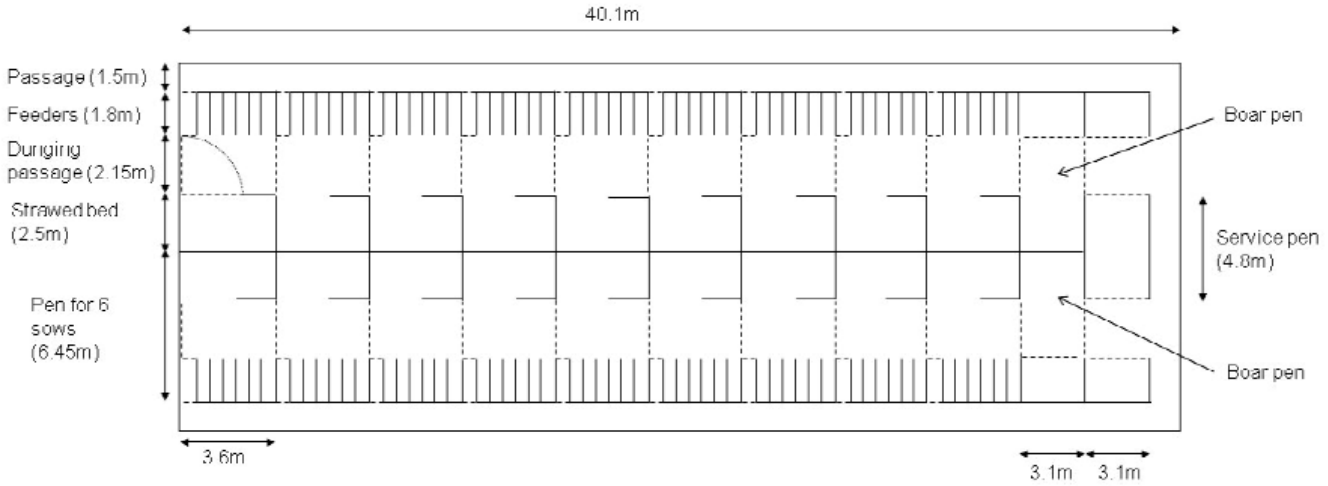

Diagram of dry-sow house where the study was carried out, including dimensions (not to scale). Dashed lines indicate barred gates, shown in their normal position. The top left pen indicates the arc of gate swing to show how gates can be temporarily closed to shut sows into the straw-bedded area for mucking out and for locomotion scoring. Sows were observed while being moved from one of the sow pens, along the dunging passage, into the service pen and back again.

'sampling intensity' on reliability of measures. These include studies of changes over time with repeated visits (Winckler *et al* 2007), the effect of sampling different numbers of animals at each visit (Mullan *et al* 2009; Main *et al* 2010), inter-observer reliability (Brenninkmeyer *et al* 2007; Bokkers *et al* 2009) and test-retest reliability (O'Callaghan *et al* 2003; Flower & Weary 2006; Bokkers *et al* 2009). These questions are not merely academic: animal-based scoring systems could, and perhaps should (eg FAWC 2008), become the basis on which producers are deemed to pass or fail the criteria of an assurance scheme, so certain standards of reliability must be reached (de Passillé & Rushen 2005). Using locomotion scoring to detect lameness in sows as an example of an animal-based scoring method, the present study investigated the extent to which individual sows varied over time in their scores, and whether scores were affected by parity and stage of pregnancy or veterinary treatment. Observers had different levels of experience with sows, and were all initially naïve to the scoring system, so the extent to which experience with the system improved consistency in the absence of training in these varied observers was also examined.

Lameness occurs in a variety of captive species, and is of welfare concern as the animal experiences pain, discomfort and reduced mobility (Knowles *et al* 2008; Flower & Weary 2009). Lameness has production costs too due to costs of treatment and is responsible for premature culling of around 7–11% sows (Lucia *et al* 2000; Anil *et al* 2005, 2009; Engblom *et al* 2007; Jensen *et al* 2010).

Although automated methods of assessing lameness have been investigated (Gonzalez *et al* 2008; reviewed in dairy cattle by Flower & Weary 2009), simple human observer scoring systems are still the main method used as they are relatively cheap, reliable and easy to apply on-farm (Pigs: Main *et al* 2000; KilBride *et al* 2009, 2010; Cattle: Winckler & Willen 2001; Flower & Weary 2006, 2009; Rutherford *et al* 2009; Chickens: Kestin *et al* 1992; Garner *et al* 2002). For sows in most countries, confinement in stalls during pregnancy and crates during farrowing and lactation makes on-farm assessment of lameness difficult, as altered posture is most likely not as sensitive a measure of lameness as locomotion scoring (KilBride *et al* 2010). Confinement, thus, potentially obscures the extent of the problem. The move to group housing following the EU ban on individual stalls during pregnancy (Council Directive 2001/88/EC 2001) in 2013 will both increase the need for good locomotion in sows and make lame sows easier to identify.

In the present study, locomotion scoring was applied to group-housed sows (*Sus scrofa*) on one farm, using multiple observers at each scoring event to measure inter-observer reliability. Agreement between observers was assessed in terms of: i) absolute differences; ii) exact matching; and iii) association. Although these are conceptually and statistically complementary approaches, they are rarely all used on the same dataset (but see Kaler *et al* 2009). Since the same sows were scored on several occasions, additionally consistency of scores over time was also investigated, and the factors affecting locomotion scores such as sow parity, stage in the reproductive cycle and the application of veterinary medicines.

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Table 1 The lameness scoring system used in this study. Observers used the integer scores as instructed, on all but four occasions when an intermediate score (eg 1.5) was recorded.

Score	Label	Description
0	Normal	Even strides, rear end sways slightly while walking, pig is able to accelerate and change direction rapidly. Stands normally
1	Stiff	Abnormal stride length, movements no longer fluent, pig appears stiff. Pig still able to accelerate and change direction. Stands normally
2	Slight lameness	Shortened stride, lameness detected, swagger of rear end while walking, no hinrance in pig's agility. Uneven posture while standing
3	Lame	Pigs slow to get up (may dog sit), shortened stride, minimum weight-bearing on affected limb (standing on toes), swagger of rear end while walking. May still trot and gallop
4	Limping	Pig reluctant to get up, holds limb off floor while standing, avoids placing affected limb on the floor while moving
5	Downer	Pig unresponsive: does not move and struggles to stand when encouraged to do so

Materials and methods

Study animals and housing

One hundred and fifty-four Large White × Landrace sows at SAC's research pig unit were the subjects of this study. The study animals included maiden gilts up to parity-seven sows (mean [± SD] parity = 2.89 [± 1.72]), and included dry sows at various stages from soon after weaning (waiting to return to oestrous and be served) through to heavily pregnant sows. They were housed in groups of 1–6 (4.5 [± 1.6]) to a pen. Figure 1 shows the building where the sows were housed during the study. The pens (3.60 × 6.45 m; length × width) were concrete-floored, with an enclosed straw-bedded area at the rear (3.60 × 2.50 m), walled with concrete blocks, with a 2.0-m wide opening onto a solid-floored central dunging passage (3.60 × 1.95 m), and an access passageway plus six individual feeding stalls side-by-side at the front (each 1.80 × 0.50 m). Sows were fed on a rationed quantity of a commercial sow diet suitable for their size/age and stage of gestation once a day (0800h). At each side of the pen was a barred gate across the width of the dunging passage, which could be swung across to shut the sows into the bedded area (Figure 1). Water was available in each pen via a nipple drinker mounted on one of the gates. The pens were arranged in two back-to-back rows of nine pens (108 sow places) and an automated natural ventilation system set at 14.5°C maintained a temperature of 8.1–21.6°C (min to max), mean 16.2 (± 4.1)°C during the study. At one end of the building, there was an empty concrete-floored service pen, with a small amount of straw and 3-cm deep sawdust (4.8 × 3.1 m), used for artificial insemination, positioned adjacent to where two 'teaser' boars were individually housed.

Locomotion scoring

Sows were locomotion-scored in two contexts: i) systematic dry-sow-herd scoring, where all sows currently in the dry-sow house were scored at one time; and ii) scoring of sows due to farrow, or recently weaned sows when they were being moved to or from their farrowing accommodation.

Dry-sow-herd locomotion scoring

This took place on eleven occasions in total. The first two scoring events took place six months apart, but after that they took place at intervals one to two months (27–202 days apart; 56 [± 53.9 days]) over a period of 566 days between December 2008 and June 2010. There was turnover in the breeding herd (old sows being culled, new gilts coming in) and a proportion of sows were in the farrowing house at any one time. As such, between 47 and 76 (67.6 [± 8.4]) sows were scored at each scoring event, and individual sows were scored on 1–10 occasions (4.79 [± 2.66]).

Between three and five observers (3.95 [± 0.65]) were present at each scoring event. Observers B and C attended all eleven scoring events, A and D attended nine events and observer E attended four. Each observer independently assigned each sow a locomotion score according to the system shown in Table 1 and did not discuss or compare scores with other observers. The scoring system was simplified from the system developed by Main *et al* (2000) for growing pigs (see also KilBride *et al* 2009). Observers were also free to record comments for every sow. For the dry-sow-herd scoring, observers consisted of a scientist with practical pig experience over a period of eleven years, but now primarily desk-based (A; the author), whose interaction with these sows was limited to the scoring sessions only, another scientist (B) with 8.5 years of regular experience with sows in general, and running a project involving these particular sows, the pig unit manager (C) with over 28 years experience working with all ages of pigs every day, and two technicians (D) with 3.5 years and (E) 18 years experience of regularly working with pigs, including these sows. Before scoring began, the scoring system was explained and discussed by the observers to ensure it was well understood, but no formal training was undertaken.

In the morning prior to scoring taking place, sows were spray-marked for ease of identification. Scoring began at 1330h and took approximately 45–70 min. First, all sows on one side of the dry-sow house (Figure 1) were shut into their bedded area, and then the group furthest from the service

area was let out of their pen and moved to the service pen. Sows either walked or ran, and some required encouragement to walk from a stockperson walking behind them. During scoring, it sometimes became apparent that sows were difficult to move. These were scored by all observers present and then sows which were slow to move (scoring 4 'limping') were only moved a short way before being returned, while those scoring 5 'downer' were scored in their home pen. Once sows had been moved to the service pen, they were shut in for 3 to 5 min, with one person who moved amongst the sows encouraging them to move to facilitate scoring. Sows were then returned to their home pen, where they were no longer shut into the bedded area. Then, the next group was moved to the service pen in a similar way, and so on for all the pens of sows until one side of the building was complete, then the procedure was repeated for the other side of the building. While sows were moving to the service pen, in the service pen and moving back, they were continually observed and scored by the observers. Scorers made sure to focus on each individual sow for at least ten strides of walking during this period and to give their score once this was complete. Sows which were identified as scoring three or higher which had not previously been identified during the course of normal husbandry were examined following scoring and subsequently given appropriate veterinary treatment. This occurred on 13 occasions during the study. Depending on the suspected cause of the lameness, sows were treated with different combinations of drugs. Eight sows were given 5 ml of the non-steroidal anti-inflammatory drug Metacam (Boehringer Ingelheim Ltd, Bracknell, Berks, UK); usually once, but for two sows this was repeated daily for up to seven days. A three-day course of the antibiotic depocillin (Intervet, Milton Keynes, Bucks, UK) (8–12.5 ml depending on weight) was given to eight sows and a broad spectrum antibiotic (Baytril [Bayer, Newbury, Berks, UK]) (8 ml) was also used on two occasions.

Farrowing sow locomotion scoring

For 123 of the sows, locomotion scoring took place prior to farrowing and after weaning. When they reached 109 days after service, (4.38 [± 1.84] days before farrowing), they were moved out of the dry-sow house, across a concrete outside area, into a separate farrowing building and placed individually in loose-housed (non-crate) farrowing pens (PigSAFE; Baxter *et al* 2011). They were locomotion-scored as they walked. The scoring was all carried out by observer B (a scientist). Once their piglets were weaned (26.8 [± 3.1] days after farrowing), sows were moved back to the dry-sow house, and were again locomotion scored as they walked between buildings.

Statistical analysis

The nature of the dry-sow-herd locomotion scoring data led to a number of challenges for analysis. The data were incomplete because not every sow was present at each scoring event: sows were sometimes in the farrowing house, and there was some turnover in the herd (culls and replacements) during the study period. Also, not every observer was able to attend every scoring event. So there were a lot of 'missing' data where a particular sow/observer/scoring-event combination did not occur.

Non-linear mixed models for ordinal data (using SAS; Gilmour *et al* 1987; Keen & Engel 1997) were fitted for each event separately to assess inter-observer reliability. An underlying latent continuous variable for locomotion was assumed of the form: $y_{ij} = \beta_0 + u_i + e_{ij}$ where u_i is a sow-level normal random effect and e_{ij} are independent and identically distributed normal errors. y_{ij} was estimated from observer scores. The 0–5 scoring scale corresponds on the latent variable scale to six intervals: $(-\infty,0)$, $(0,I1)$, $(I1,I1+I2)$, $(I1+I2,I1+I2+I3)$, $(I1+I2+I3,I1+I2+I3+I4)$ and $(I1+I2+I3+I4,\infty)$ where I1, I1+I2, I1+I2+I3, I1+I2+I3+I4 are the thresholds for the categories. They were estimated when a threshold model for the latent variable was fitted as a generalised linear mixed model (GLMM) using the NLMIXED procedure in SAS 9.1 (SAS Institute Inc, SAS, Cary, NC, USA). Inter-observer reliabilities were derived from the variance components. In practice, scoring categories had to be merged on an event-by-event basis to enable model fitting when there were very few animals on specific scores.

A different approach to dealing with the 'missing' data was used to look at consistency over time in sow locomotion scores. A subset of the data was used: 81 sows which were scored on four or more occasions by the four observers that did the most scoring (A–D), were identified. Kendall's coefficient of concordance was calculated across the first four scoring events for each sow, using the mean of the four observers' scores at each one. Note that the four specific scoring events used could vary between the sows in this subset.

Another challenge for model fitting was that there were a high proportion of zero scores in the data. To model the different factors affecting locomotion scores (sow parity and stage of pregnancy), the scores were first re-coded into 0–1 data ($0 \rightarrow 0$, $1–5 \rightarrow 1$) and a Generalised Linear Mixed Model was used to fit a binomial model (with a logit-transformation; Genstat 11th Edition), with sow as a random effect, and observer, scoring event, sow parity and days until next farrowing (either actual or estimated from service records) as fixed effects (with parity and days until next farrowing being fitted as covariates). Note that non-pregnant sows and pregnant sows were treated similarly in this analysis: non-pregnant sows were simply those with greater than 113 days until next actual or predicted farrowing.

The effect of veterinary treatment on sow locomotion score was analysed by comparing scores for each observer using paired Wilcoxon signed ranks test. Scores from 0 to 90 (32.8 [± 24.6]) days before treatment began were compared with scores from 6 to 190 days after (57.3 [± 54.3]). One observer (B) was present for all 13 of the relevant scoring events, but other scorers had some missing data (A = 8 events, C = 12, D = 10).

Various non-parametric methods were applied to measure inter-observer reliability. These require that there was no missing data at all, so data from the 498 occasions when four of the observers (A, B, C and D) were present was used

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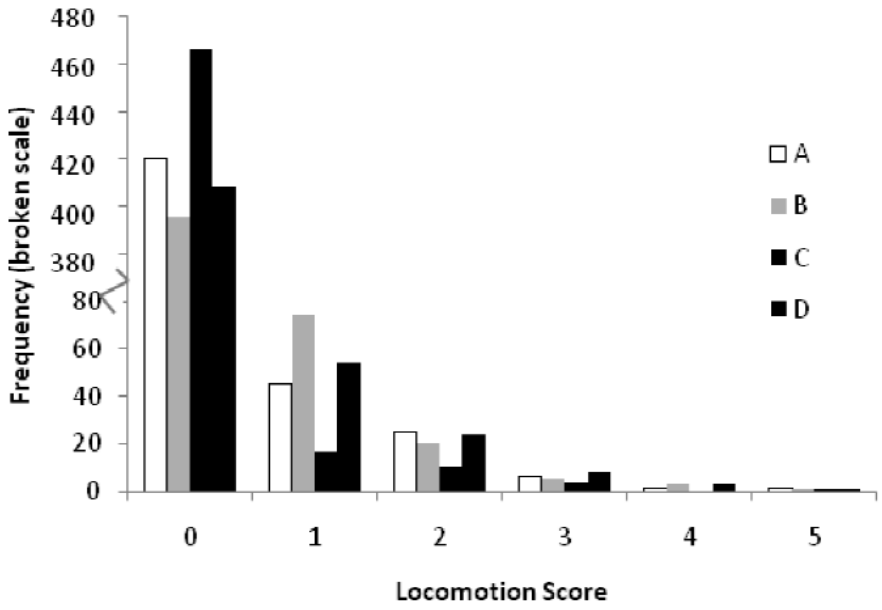
Figure 2

Frequency of locomotion scores given overall by four different observers (A, B, C and D). This data are all scores generated by these four observers used in the study (ie for all sows at all scoring events), so includes repeat observations of the same sows. Note the broken scale on the Y-axis.



(eight scoring events: 1, 3, 4, 6, 7, 8, 9 and 10; which included 137 sows). Using these data, three aspects of agreement were considered:

i) Whether observers differed systematically in the absolute level of scores awarded. This was assessed using Friedman for an overall comparison, and Sign tests and Wilcoxon signed rank tests (Minitab 15, 2006) to compare each pair of observers.

ii) Whether scores from different observers matched exactly. Proportion of agreement and kappa were calculated overall, by pairs of observers, and for different scores (Minitab 15, 2006). The Prevalence Adjusted Bias Adjusted Kappa (PABAK; Byrt *et al* 1993) was also calculated as this is preferred by some researchers (Brenninkmeyer *et al* 2007; Rutherford *et al* 2009). Weighted kappa (using linear weightings) were also calculated (AgreeStat Excel workbook, Advanced Analytics 2010). In interpreting kappa and PABAK, the scale suggested by Byrt (1996) was used: 0 or less no agreement, 0.01–0.20 poor agreement, 0.21–0.40 slight agreement, 0.41–0.60 fair agreement, 0.61–0.80 good agreement, 0.81–0.92 very good agreement, 0.93–1.00 excellent agreement. Finally, kappa statistics were calculated following a re-coding of the 0–5 data to 0–1 data in two different ways: either all scores above zero were re-coded as 1 (0 → 0, 1–5 → 1), or 0 and 1 were re-coded as 0, and higher scores as 1 (0 and 1→ 0, 2–5 → 1). This was done for comparison with other researchers who have scored animals in two categories of 'sound' and 'lame' (eg Rutherford *et al* 2009). Two different approaches were chosen because of the difficulty in classifying score '1' animals (see *Results*).

iii) Whether scores from different observers were associated. This was assessed using Kendall's coefficient of concordance (*W*; Genstat 11, VSN International Ltd 2008) as a measure of overall agreement, and Spearman's (ρ) and Kendall's (τ) rank correlation coefficients were calculated between each pair of observers (Genstat 11, VSN International Ltd 2008).

Finally, farrowing sow locomotion scores from before farrowing and after lactation were compared using Wilcoxon signed ranks test for paired data (after calculating differences, data were not normally distributed).

Ethical note

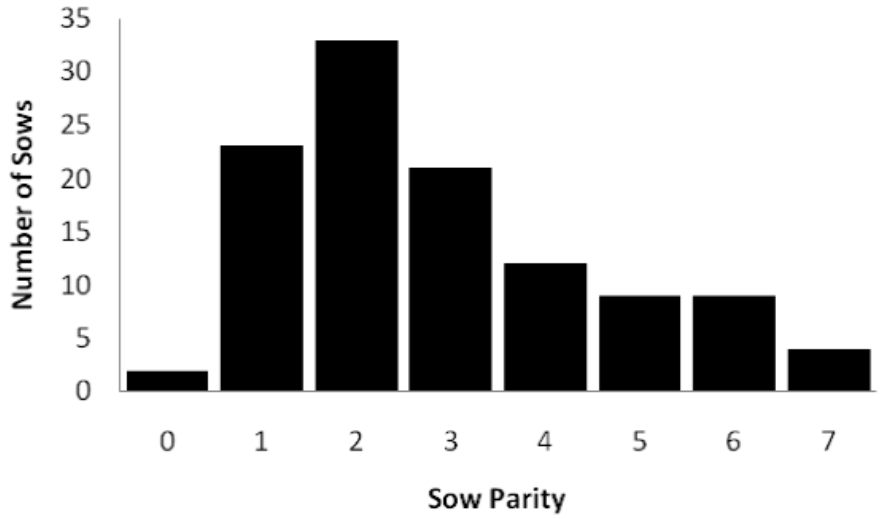
This study was given ethical approval by SAC's Animal Experiments Committee. As detailed above, any sows which scored 3 or higher (3 'lame', 4 'limping', 5 'downer') were given appropriate veterinary treatment, while those scoring 1 or 2 were investigated and treated if necessary. Since sows were being checked daily as part of their routine husbandry, it was rare for lameness problems to be newly identified as part of the scoring process.

Results

Distribution of scores

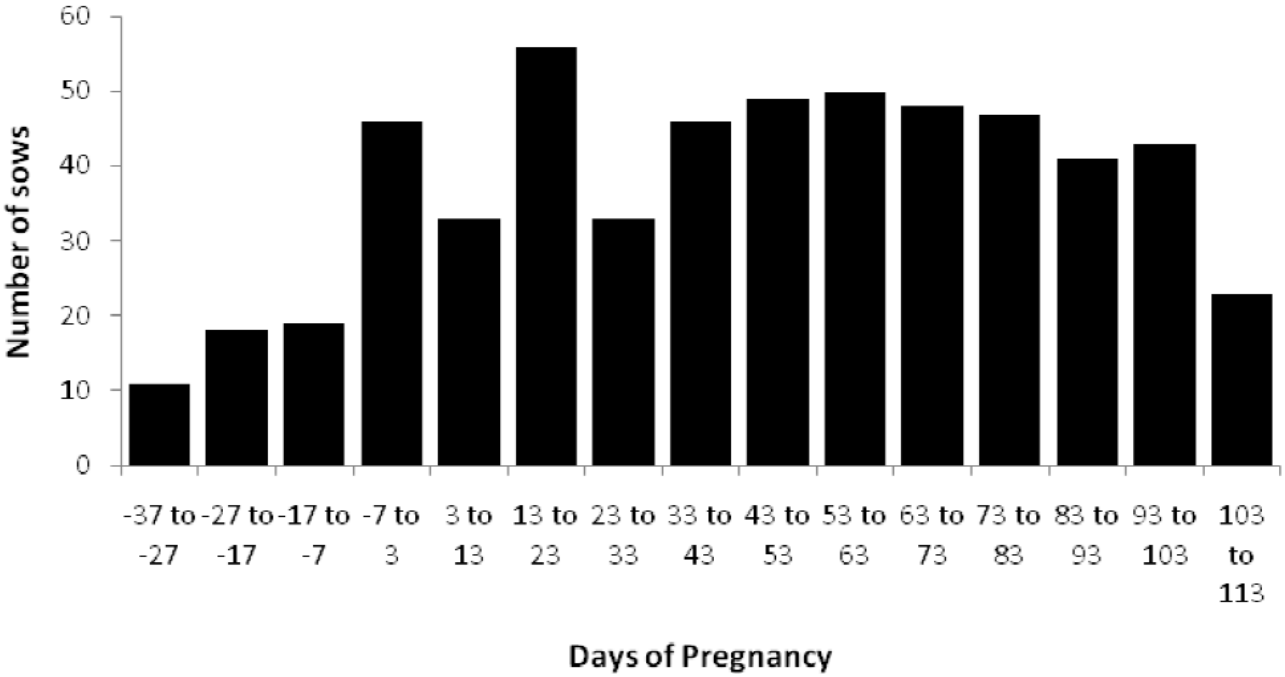
The frequency of scores given overall by each of the observers (ie for all sows over all scoring events) is shown in Figure 2. The vast majority of scoring events resulted in the observer giving the sow a score of 0: normal (mean % of scores at each level — 0: 84.8%, 1: 9.5%. 2: 4.0%, 3: 1.2%, 4: 0.4%, 5: 0.2%).

Figure 3



Histogram showing the distribution of sow parities at the end of the study. Sows which have not yet been served are shown as parity 0, parity 1 sows have produced one litter etc (n = 113, data not available for 41 sows).

Figure 4



Histogram showing the number of sows at each stage of pregnancy. Sows were usually moved into the farrowing house 109 days after service (n = 563 for this graph as individual sows can appear repeatedly).

Consistency of repeated scores from the same individual sows

To estimate consistency over time of sow scores, the mean locomotion score of observers A–D, from 81 sows at four scoring events were used. These scores for this subset were distributed similarly to the dataset as a whole as follows: 78.1% had mean score 0, 16.4% had a mean score between 0.25 and 1, 4.0% had a mean score between 1.25 and 2, 1.5% scored 2.25 or higher. There was a significant moderate level of association between sows: Kendall's $W = 0.496$, $P < 0.001$, suggesting that individual sows showed similar scores over repeated scoring events.

Factors affecting locomotion score

GLMM models showed that there were differences in locomotion scores (re-coded to 0–1) due to observer (Wald statistic $\chi^2_4 = 114.22$, $P < 0.001$) and scoring event: inspection of estimated means showed that scores were lower at later scoring events ($\chi^2_{10} = 38.02$, $P < 0.001$). A histogram

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Table 2 Inter-observer agreement statistics

	Sign test (–ve: +ve)	Friedman or Wilcoxon test	Spearman's (ρ)	Kendall's *W* or τ	Kappa (κ)	Weighted kappa (κ_w)	Kappa (κ) after combining categories (sound = 0, lame = 1+)	Kappa (κ) after combining categories (sound = 0 or 1, lame = 2+)
Overall (A-B-C-D)		102.66***		0.692***	0.443***	0.582	0.532	0.653
A-B	53: 28**	1,199.5*	0.604***	0.591***	0.482***	0.629	0.549	0.725
A-C	8: 64***	2,352.5***	0.536***	0.524***	0.289***	0.457	0.440	0.478
A-D	46: 28*	1,047.5†	0.643***	0.626***	0.498***	0.642	0.599	0.704
B-C	6: 85***	3,863.0***	0.457***	0.448***	0.249***	0.416	0.335	0.574
B-D	24: 29	754.0	0.781***	0.771***	0.679***	0.777	0.750	0.852
C-D	74: 5***	160.0***	0.555***	0.541***	0.290***	0.459	0.439	0.488

Differences between observers' scores. Friedman test for effect of the four observers on locomotion score, blocked by sow event. For pair-wise comparisons using Sign and Wilcoxon signed ranks tests: the score for the second observer was subtracted from the score for the first observer (eg for A-B difference = A minus B), so +ve difference means the first score was higher (eg A's score higher than B's). Association between pairs of observers' scores as calculated by Spearman's rho (ρ) correlation coefficient and Kendall's tau (τ) correlation coefficient, Kendall's coefficient of concordance (*W*) between multiple observers is also given. Agreement (exact matching) between observers' scores given by Fleiss's kappa (κ) for four observers and Cohen's Kappa (κ) for pairs of observers. Weighted Kappa is also shown (using a linear decline in weightings further from the diagonal). Finally, kappa (κ) calculated after re-coding the data to 1–0 form using two different methods is shown. In the first method, all scores of 1–5 were re-coded as 1 ('lame'), and in the second method, scores of 0 and 1 were re-coded as 0 ('sound'), while scores of 2–5 were re-coded as 1 ('lame'). † $P < 0.1$; * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

showing the distribution of sow parities in the study is shown in Figure 3. Older (higher parity) sows had higher locomotion scores ($\chi^2_1 = 3.98$, $P = 0.049$). A histogram showing the distribution of stage of pregnancy is shown in Figure 4. There was no effect of stage of pregnancy ($\chi^2_1 = 0.10$, ns). Locomotion scores observed before and after sows were given veterinary treatment for lameness did not differ for any observer.

Agreement between observers — do they differ?

From this section forward, all analyses (unless stated otherwise) use data from the 498 occasions when observers A–D were all present, as the mainly non-parametric methods used require no missing data. There were differences between the observers in the proportion of sows scored in each category. Observer C (pig unit manager) recorded a higher proportion of zeros than the other observers (Figure 2). A Friedman test comparing observers for the same sow on the same occasion showed a highly significant difference between observers, and inspection of the sums of ranks showed this was because observer C's scores were lower than those of the other three observers ($S = 102.6$, $P < 0.001$; sums of ranks A = 1,252, B = 1,299, C = 1,143, D = 1,286). When pairs of values were compared with Sign and Wilcoxon tests, these confirmed that observer C was scoring lower than the other three, and observer A gave lower scores than B and D, who did not differ (Table 2).

Agreement between observers — do they match?

Raw proportions of agreement both overall and between pairs of observers were high (Table 3). The proportion of agreement was considerably higher for 0 than for other scores. This is best illustrated by the proportion of occasions on which all four observers agreed to give the same score (first row of Table 3). The overall kappa statistic of 0.443 is at a level which suggests only 'fair' agreement (Byrt 1996), although the PABAK statistic at 0.692 suggests 'good' agreement.

When broken down by scores (Table 3), kappa and PABAK were noticeably lower for score 1, perhaps reflecting the difficulty in identifying and agreeing on the threshold between 0: 'normal' and 1: 'stiff', a score used for minor locomotor anomalies.

When broken down by pairs of observers (Table 2), values of kappa (and of weighted kappa and kappa following combining of categories) were considerably lower for pairings involving observer C (A–C, B–C and C–D) than for the other three pairings. Pairings which include observer C suggest 'slight' agreement, while pairings including observers A, B and D agreed at 'fair' or 'good' level. Contingency tables of the frequency of scores given by observer pairs B and D (Table 4) and B and C (Table 5) are shown to illustrate good and poor agreement, respectively. For observers B and D, scores which differ by 2 are rare, and the greatest number of discordant scores occurs at the 0 vs 1 level. For Table 5 (observers B and C, poor agreement),

Table 3 Raw proportions of agreement between observers broken down into overall agreement (all four observers agree) and agreement between pairs.

	Agreement		Proportion of agreement					
	(n/498)	Overall	0	1	2	3	4	5
Kappa (κ)		*0.443*	*0.532*	*0.279*	*0.486*	*0.458*	*0.379*	*1.00*
PABAK		*0.692*	*0.834*	*–0.176*	*0.040*	*0.004*	*–0.20*	*1.00*
Overall								
(A-B-C-D)	370	**0.743**	**0.862**	**0.020**	**0.200**	**0.170**	**0.000**	**1.000**
A-B	417	**0.837**	0.918	0.370	0.667	0.727	0.500	1.000
A-C	426	**0.855**	0.937	0.097	0.229	0.600	0.000	1.000
A-D	424	**0.851**	0.932	0.364	0.612	0.429	0.500	1.000
B-C	407	**0.817**	0.906	0.198	0.333	0.444	0.000	1.000
B-D	445	**0.894**	0.951	0.641	0.727	0.462	0.667	1.000
C-D	419	**0.841**	0.929	0.169	0.294	0.167	0.000	1.000

Proportions are worked out using n = 498 as the denominator for calculations of overall agreement. For separate score proportions (for 0, 1, 2, 3, 4 and 5), the denominator was worked out as the average number of scores awarded at that level, either overall (scores in bold) or by that pair of observers. The kappa statistic (κ) and the Prevalence Adjusted Bias Adjusted Kappa (PABAK) are also given in italics overall and broken down by score.

Table 4 Contingency table of scores for observer B and D to illustrate good agreement. Exact matches (on the diagonal, in bold) were summed to give the agreement, which was then expressed as a proportion (of 498; see Table 3).

		Observer D sow locomotion scores						
		0	1	2	3	4	5	Totals
	0	**382**	12	1				395
Observer B locomotion scores	1	26	**41**	6	1			74
	2		1	**16**	3			20
	3			1	**3**	1		5
	4				1	**2**		3
	5						**1**	1
	Totals	408	54	24	8	3	1	498

Table 5 Contingency table of scores for observer B and C to illustrate poor agreement. Exact matches (on the diagonal, in bold) were summed to give the agreement, which was then expressed as a proportion (of 498; see Table 3).

		Observer C sow locomotion scores						
		0	1	2	3	4	5	Totals
	0	**390**	3	2				395
Observer B locomotion scores	1	65	**9**					74
	2	9	5	**5**	1			20
	3	1		2	**2**			5
	4	1		1	1	**0**		3
	5						**1**	1
	Totals	466	17	10	4	0	1	498

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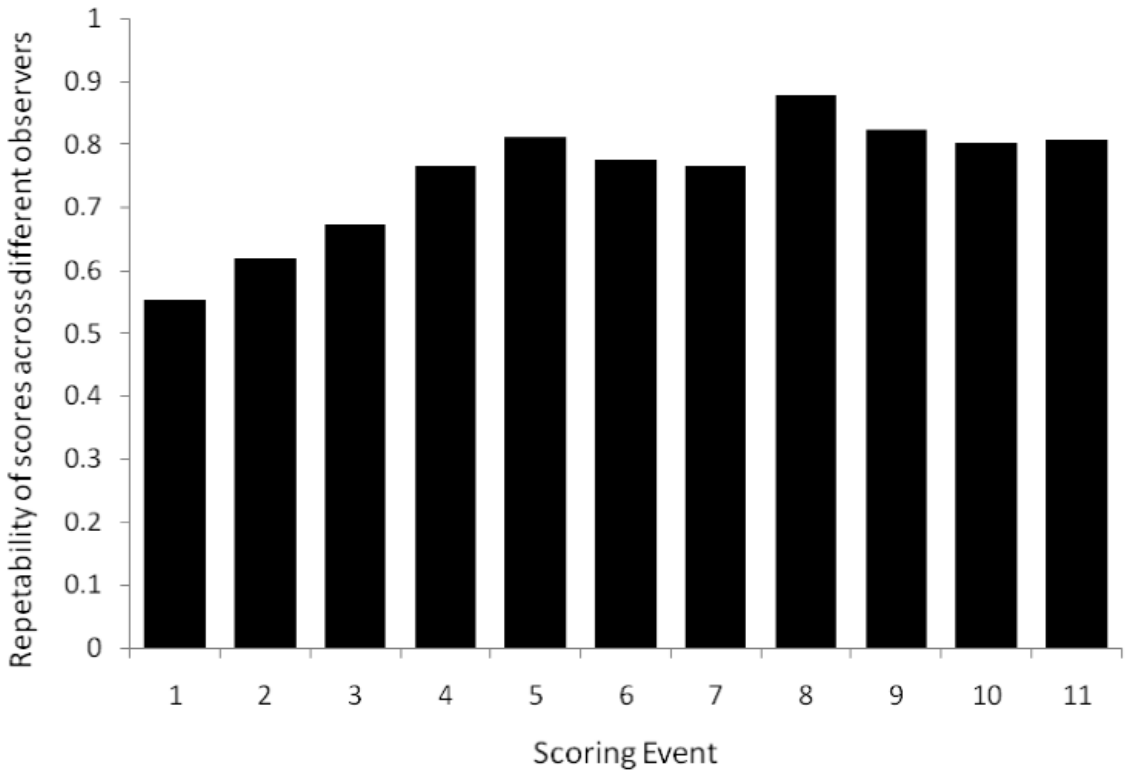
Figure 5



Repeatability of scores across different observers for the eleven scoring events, using data for all observers present at each event. Repeatability estimates were obtained using non-linear mixed models for ordinal data. A separate model was run for each scoring event.

there are more scores which differ by 2, 3 or even 4. Again, the greatest discrepancy occurs at the 0 vs 1 level.

Values for weighted kappa, which takes into account the size of the disagreement between observers (Table 2) were considerably higher than those of kappa, suggesting that disagreement by a small degree (eg by one point of the scoring system) was more common than disagreement by a larger amount.

The 0–5 scores were converted into 0–1 scores (sound/lame) by combining categories in two different ways (Table 2): i) scores of 0 were classed as 'sound' and scores of 1–5 were classed as 'lame'; or ii) scores of 0 or 1 were classed as 'sound' and scores of 2–5 were classed as 'lame'. The kappa was considerably lower for the first of these methods than for the second, consistent with the suggestion that the observers showed higher levels of agreement about the higher (2+) categories than they did about the distinction between 'Normal' (0) and 'Stiff' (1) pigs.

Agreement between observers — are they associated?

Using all available data, a non-linear mixed model for ordinal data was fitted for each scoring event, to estimate inter-observer reliability. Across the eleven scoring events, reliability was moderate to high, ranging from 0.552 to 0.879. It was evident that reliability improved over time (Figure 5), reaching a plateau by about the 4th or 5th scoring event.

Using data from the 498 occasions when observers A–D were all present, Kendall's coefficient of concordance (W) showed that there was moderate agreement between the observers. Levels of spearman's ρ and kendall's τ (Table 2) for pair-wise agreement were moderate to high. Values were again lowest for pairs involving observer C, although the difference was less marked.

Because pairings involving observer C showed a lower level of agreement than other pairings, measures of agreement between the other observers, A, B and D were also calculated. Kendall's W was 0.784, Fleiss's kappa was 0.557, and weighted kappa was 0.684. These values were all higher by around 0.1 than the overall agreement measures (Table 2).

Farrowing sow locomotion scoring

The distribution of sows' locomotion scores before farrowing was 0: 83%, 1: 27%, 2: 12%, 3: 1%, and after weaning was 0: 89%, 1: 25%, 2: 7%, 5: 2%. There were no differences between the locomotion scores before farrowing and after weaning (W = 439, n for test ignoring ties = 45, P = 0.379).

Discussion

The right-skewed distribution of scores (Figure 2) was as expected. This shape of distribution is common in locomotion scoring studies (eg KilBride *et al* 2009). Levels of sow lameness in the present study were comparable to previous reports: KilBride *et al* (2009) studied 88 UK herds and found that 14.4% of pregnant gilts and 16.9% of pregnant sows had abnormal gait (score of 1 or higher), while 1.0 and 1.8% had minimal weight-bearing on an affected limb (score 3 or higher). Respective figures for the present study of 15.2 and 1.8%. Further studies are needed to assess the welfare significance of these scores (Main *et al* 2000), but it seems likely that reduced weight-bearing on the affected limb is indicative of some discomfort/pain. Approaches to measure the welfare significance of locomotion scores include the use of motivational measures (Weeks *et al* 2002) or analgesics (Danbury *et al* 2000; Rushen *et al* 2007; Flower *et al* 2008), but these have not as yet been applied to pigs.

The structure of the dataset, with inevitable 'missing' data as sows moved through the system, complicated the analysis of consistency of sow scores. Kendall's coefficient of concordance using the average of four observers showed a moderate level of consistency. This analysis corresponds with studies in dairy cows which reported a degree of consistency over time in locomotion scores (De Rosa *et al* 2003; O'Callaghan *et al* 2003). It suggests that sow lameness is often a chronic problem. Although veterinary treatments were only applied on 13 occasions during the study, there was no evidence that scores were improved after treatment compared with before. This result should be viewed with a degree of caution: it was not the primary aim of the study, and sample size was very low. Also, there was a large and variable amount of time between the treatment and the before and after scores. The treatments may well have worked well in the short or even long term, but new causes of lameness may have occurred before the next scoring event.

Analysis of predictive variables found that locomotion score (analysed as binomial data, 0 vs 1–5) was affected by parity but not stage of pregnancy. Parity may have affected locomotion score because heavier animals are more likely to become lame (because of the greater pressure on their feet and joints), or because older sows have had longer to pick up an accidental injury which may then take some time to resolve. In dairy cow studies, size, conformation and udder fill affect how cows walk (reviewed by Flower & Weary 2009), and weight affects broiler locomotion scores (Kestin *et al* 1992). During this study, observers commented that they had had difficulty with the lowest end of the scoring system. It was felt that the system failed to reflect the diversity of 'normal' and 'abnormal' gaits, particularly in sows differing in age, weight or stages of pregnancy. For example, 'swagger of rear end while walking' (2– 'slight lameness') was fairly pronounced in some otherwise normal older sows, so the effect of parity on locomotion score may partly reflect this change in gait of older sows, as any deviation from score 0 would have affected this analysis.

In terms of recommendations for welfare assessment study design and sampling intensity, the variation across parities suggests that the sampling strategy of larger on-farm studies should take this into account, ensuring that a representative cross-section of the range of parities on the farm is sampled. The moderate consistency over time in sow scores suggests that locomotion scores do not change rapidly over time, so infrequent visits should give a fair representation of the typical locomotion score of a given herd. However, these recommendations are tentative. A larger study specifically addressing the question of sampling methods would be desirable (see, eg Mullan *et al* 2009; Main *et al* 2010).

Three aspects of agreement between observers were analysed. Absolute differences between observers will be considered first. Variation of this type is particularly problematic when absolute consistency is required, for example in order to compare the actual level of lameness between different farms or studies. In our study, the farm manager (observer C) used lower scores and more zeros than other observers and his scores did not match or agree as well with those of other observers. While being cautious not to over-interpret this finding from a single observer, it is notable that in dairy cattle, farmers as a group generally underestimate the incidence of lameness in their own herd (Wells *et al* 1993; Whay *et al* 2003; Rutherford *et al* 2009; Leach *et al* 2010). In a study of lameness in sheep, farmers were asked to estimate the prevalence of lameness and then carry out direct animal-based scoring. Prevalence recorded was higher from animal-based scoring (than from their initial estimate) but scores were still systematically lower than those of a researcher whilst showing good agreement (correlation) with them (King & Green 2011). It is possible that farmers usually categorise low levels of lameness as 'normal', because the key thing for them is to identify the level at which the threshold for treatment occurs (King & Green 2011). Alternatively, since farmers primarily spend time with their own animals, on a farm with widespread low levels of lameness, this may become the 'new normal'.

A different interpretation of this finding would be that observer C was correct, and that the other, less-experienced observers, over-scored. In particular, the farm manager may have had more experience of the range of 'normal' gaits in older sows (see observers' comments above). Farmers and scientists have different perspectives on animal welfare which may affect their interpretation of the same scoring scheme (Hubbard & Scott 2011).

Observer agreement in terms of matching of scores will be considered next. The overall kappa statistic suggested fair agreement, although the PABAK statistic was higher suggesting good agreement (Byrt 1996). This difference probably arises because kappa does not simply reflect 'agreement' but can be affected by bias, where there are systematic differences between observers, and prevalence, where the distribution of scores is not uniform (Byrt *et al* 1993). Both bias and prevalence were clearly issues in this dataset, and the PABAK statistic is intended to adjust for these. Rutherford *et al* (2009) reported a mean PABAK of 0.88 (range 0.67–0.94) between three or more trained observers (after scores were pooled into 'sound' and 'lame' categories) in a study of dairy cattle lameness. The PABAK

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of 0.692 for the six-level scoring system in the present study (Table 3) is fairly good in comparison. The level of agreement was comparable to a dairy cow locomotion study by Winckler and Willen (2001) in which the proportion of agreement between three observers was 0.68, while the present study found a slightly higher level of 0.743 between four observers (Table 3).

When analysing agreement at each score level, kappa and PABAK were lower for score 1, suggesting poorer agreement. Work in sheep (Kaler *et al* 2009) and cattle (Flower & Weary 2006) has also shown that agreement is better for higher scores distinguishing between the lowest level (normal) and next level up is often the most difficult. Winckler and Willen (2001) found that 62% of disagreements between observers were at this level, and two other studies found much improved agreement after merging the lowest 2 scores and the top 2 (or 3) scores into simpler non-lame and lame categories (Brenninkmeyer *et al* 2007; Rutherford *et al* 2009).

Finally, I applied methods of agreement based on association or near matching. Again, levels of agreement found were comparable to other studies. Flower and Weary (2006) reported an R^2 from regression of 0.69 between two observers, which equates to correlation coefficient (r) of 0.83, higher than the best pair-wise agreement measured by spearman's ρ (0.781) or Kendall's τ found in this study (0.771; see Table 2). Higher levels of association and matching and lower levels of difference between observers than those found here have been reported in a study of sheep lameness (Kaler *et al* 2009). This may be due in part to the use of video sequences in this study rather than live scoring.

Mixed models showed that inter-observer reliability improved over time and then plateaued at around event 4 or 5 (Figure 3). This suggests that observers showed better agreement with each other with experience, probably because each showed more internal consistency and perhaps also because after each session observers discussed their experience with the method and how to deal with certain examples or borderline cases. Other studies have shown that locomotion scorers show higher levels of agreement with increasing experience (Main *et al* 2000) or with more training (Brenninkmeyer *et al* 2007; March *et al* 2007; Thomsen *et al* 2008).

Overall, methods to analyse agreement in terms of absolute scores, exact matching and association or near matching all showed that observers did not agree perfectly, typically showing 'moderate' agreement. The levels of agreement were largely in line with other studies of this type which rely on visual assessment and ordinal scoring systems. Ways in which such locomotion scoring systems could be improved are discussed further below. It was notable that agreement for score 1 was poorest and observers reported difficulties with the lower end of the scale. Improved kappa values were obtained when data were combined into 0 and 1 vs 2+, suggesting that a simple sound/lame system would be preferable, as agreement is better (Brenninkmeyer *et al* 2007; Rutherford *et al* 2009). The three levels in the Welfare Quality® protocol for pigs are equivalent to scores 0–2 ('normal or altered gait' but 'still using all legs'), score 3 ('minimum weight-bearing on affected limb') and scores 4–5 ('no weight-bearing on affected limb or unable to walk'; Welfare Quality® 2009). Others have advocated more complex scoring systems to pick out specific types of abnormality (O'Callaghan *et al* 2003; Flower & Weary 2006). These might be more precise for research purposes or where early diagnosis for intervention is a priority. If simpler systems are more reliable, these might be better for on-farm overall welfare assessment.

What is the ideal locomotion scoring system?

For any locomotion-scoring system based on visual scoring by human observers (and indeed for welfare scoring systems in general), the following attributes are desirable: i) easy to use and efficient to carry out on a variety of experimental and commercial situations; ii) objective, unambiguous descriptions of each score (Garner *et al* 2002); iii) external validation (Knierim & Winckler 2009), for example against foot pathologies (Flower & Weary 2006; KilBride *et al* 2010; Kaler *et al* 2011), analgesics (Danbury *et al* 2000; Rushen *et al* 2007; Flower *et al* 2008) or other behavioural measures, such as in broiler chickens latency to lie down in shallow water, which is aversive for them, was associated with locomotion scores (Weeks *et al* 2002); iv) training before scoring 'in the field', since training and experience increase agreement between observers (Brenninkmeyer *et al* 2007; March *et al* 2007); and v) users (researchers, assurance schemes) should implement ongoing assessment of inter-observer reliability. Another interesting recent idea is to use a modified visual analogue scale, which retains the advantages of ordinal categorical scoring while adding the advantage of capturing some of the variation within categories (Tuyttens *et al* 2009).

Animal welfare implications and conclusion

Valid animal-based scoring methods to assess welfare are important both for research and for on-farm assurance purposes. This study suggested that the locomotion-scoring system used was promising, although it would benefit from external validation. Sows were moderately consistent over time in their locomotion scores, and older sows had higher scores. In terms of animal welfare, this suggests that lameness is a chronic problem and that measures to treat it are not entirely successful. In terms of animal welfare assessment methodologies, it suggests that infrequent visits to a farm might give a fair picture of the extent of lameness, provided that a representative range of sow parities was sampled, although this requires further validation in a larger study.

Inter-observer agreement can be thought of in terms of three complementary approaches: absolute differences, exact matching and association, which are all useful. Of these, the issue of absolute differences is of greatest importance in terms of 'fairness' of welfare assessment (eg comparing the prevalence of lameness between individual farms or systems). Inter-observer agreement was moderate and improved with practice, suggesting that training and regular assessment of inter-observer agreement is important to ensure standardisation of data collection methods. Agreement improved when categories

were combined: observers found minor locomotor anomalies difficult to classify. As such, a simpler system may be preferable for application of welfare assessment on-farm (eg Welfare Quality® 2009).

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