4-2009

Assessing lameness in cows kept in tie-stalls

K. A. Leach
University of Bristol

S. Dippel
University of Natural Resources and Applied Life Sciences (Vienna)

J. Huber
University of Veterinary Medicine (Vienna)

S. March
Georg-August-University of Göttingen

C. Winckler
University of Natural Resources and Life Sciences (Austria)

See next page for additional authors

Recommended Citation
Leach, K. A., Dippel, S., Huber, J., March, S., Winckler, C., & Whay, H. R. (2009). Assessing lameness in cows kept in tie-stalls. Journal of dairy science, 92(4), 1567-1574. DOI: https://doi.org/10.3168/jds.2008-1648

Authors
K. A. Leach, S. Dippel, J. Huber, S. March, C. Winckler, and H. R. Whay

J. Dairy Sci. 92:1567–1574
doi:10.3168/jds.2008-1648

Assessing lameness in cows kept in tie-stalls

K. A. Leach,*[1] S. Dippel,† J. Huber,‡ S. March,§ C. Winckler,† and H. R. Whay*
*Department of Clinical Veterinary Science, University of Bristol, Langford House, Langford, BS40 5DU, United Kingdom
†Division of Livestock Sciences/Department of Sustainable Agricultural Systems, BOKU - University of Natural Resources and Applied Life Sciences Vienna, Gregor Mendel-Strasse 33, 1180 Vienna, Austria
‡Teaching and Research Farm of the University of Veterinary Medicine Vienna, Kremesberg 13, 2563 Pottenstein, Austria
§Research Centre for Animal Production, Georg-August-University of Göttingen, Driverstrasse 22, 49377 Vechta, Germany

ABSTRACT

Identifying lame cows and quantifying the prevalence of lameness are important elements of cattle welfare assessment that are generally achieved by methods involving observations of each animal walking. There is no published method for assessing lameness in cows confined in tie-stalls. The objective of this study (carried out within the European Commission's Welfare Quality® project) was to develop a suitable method and validate it for lameness detection against a published locomotion score. A series of indicators of lameness visible in tied cows was formalized into a stall assessment protocol. This was validated against a traditional locomotion score and tested for repeatability between 2 observers. A total of 98 cows on 4 farms were assessed. Overall interobserver agreement was 91%. Sensitivity compared with locomotion scoring was 0.54 to 0.77, dependent on observer and threshold definition. Assessment in the stall underestimated the herd prevalence of lameness revealed by locomotion scoring by 11 to 37% (mean 27%). The discrepancy between herd lameness prevalence assessed in the stall and by locomotion scoring was not affected significantly by farm or observer. The cases of lameness that were not detected in the stall tended to be the least severe. The proposed method for lameness detection in tie-stalls could be used for herd-level assessment of lameness and detection of individual lame animals by farmers and their advisors, but it is important to remember that it is less sensitive than locomotion scoring.
Key words: welfare, cattle, lameness, tie-stall

INTRODUCTION

Lameness in cattle is a significant welfare problem indicating pain (Whay et al., 1997) and causing alterations to behavior (Hassall et al., 1993; Singh et al., 1993). Obtaining a measure of the prevalence of lameness is an important component of welfare assessment in dairy cattle (Whay et al., 2003). Espejo et al. (2006) reported the prevalence of lameness in 50 high-producing herds in Minnesota to be 25%. Recent figures for the prevalence of lameness in European countries range from 22% (Whay et al., 2003) to 45% (Winckler and Brill, 2004) for loose-housing systems and from <1% to 21% for systems in which cows are tied for at least part of the time (Bielfeldt et al., 2005; Sogstad et al., 2005; Zurbrigg et al., 2005). Lameness assessment is commonly achieved by gait scoring or locomotion scoring, for which a variety of methods have been developed (e.g., Manson and Leaver, 1988; Sprecher et al., 1997; Whay et al., 1997; Winckler and Willen, 2001). These involve observation of elements of gait such as length and timing of strides and relative weight bearing on the 4 feet in cows walking voluntarily. In most scoring systems, limping is a definitive parameter and some also include observations on the arch of the back or nodding of the head in the moving animal. However, such methods cannot be used in cows that are continually tied.

Despite increasing use of cubicles (free-stalls), a considerable proportion of farms in North America and Europe still keep cows tethered in tie-stalls, and not all animals are given an exercise period, even in summer. Recent reports show that 74% of dairy cows in Ontario (CanWestDHI, 2007), approximately 88% of Norwegian dairy cattle (Sogstad et al., 2005), and 75% of all Swedish dairy herds (Loberg et al., 2004) are kept in tie-stalls. A German survey revealed that 38% of organic farms had tie-stall barns (March, 2004), and 79% of respondents to a recent questionnaire sent to all organic dairy producers in Austria housed cows in tie-stalls (BMLFUW, 2007).

Although some countries are moving toward abolishing tie-stalls, this will take time. Meanwhile, a method for assessment of lameness in these situations is required. Even if herds are kept at pasture during summer, assessment may be required during the winter housing period when weather conditions or available

Received August 22, 2008.
Accepted November 15, 2008.
[1]Corresponding author: k.leach@bristol.ac.uk

Table 1. Locomotion scoring system of Winckler and Willen (2001)

Score	Criteria	Binary classification
1	Normal gait	Not lame
2	Uneven gait	Not lame
3	Short striding gait with one limb (i.e., limp visible)	Lame
4	Short striding gait with more than one limb or strong reluctance to bear weight on one limb	Lame
5	Does not bear weight on one limb or strong reluctance to put weight on limb in two or more limbs	Lame

space may be unsuitable for releasing cows to perform locomotion scoring.

Behavioral indicators of limb pain that do not necessarily involve locomotion, such as weight shifting between limbs, abnormal weight distribution and resting, pointing and rotating limbs are used in clinical diagnosis of equine lameness and have recently been reviewed by Ashley et al. (2005). However, there is limited published information on the use of such indicators in cattle. Measurements with load cells (e.g., Rushen et al. (2006) or force plates (Kujala et al., 2008) have been used to demonstrate how lame cows redistribute their weight when standing, and Whay et al. (2002) described some observations made on the posture of lame cows that were restrained. However, such descriptors have not been incorporated into a formal assessment procedure. The only recent references to assessing lameness in cows while they remain tied are those of Zurbrigg et al. (2005) and Cramer (2008), who used an arched back and hind claws rotated outwards as indicators when assessing lameness in tie-stall dairy herds in Ontario. Other studies on lameness in tied cows have focused on examination of the feet; therefore, moving cattle to the claw trimming crush gave an opportunity for locomotion scoring (Manske et al., 2002; Bielfeldt et al., 2005; Sogstad et al., 2005; Fjeldaas et al., 2006). Cook (2003) and Regula et al. (2004) released cows individually from their stalls to assess locomotion, but this may not be feasible in welfare assessments because of constraints imposed by time, staff availability, building design, and cows that are unaccustomed to freedom. Therefore, a method of assessing cows in stalls is needed. It is important to know how the results from such a method compare with those from conventional locomotion scoring, both for validation and to determine whether prevalence results from herds that are assessed by the 2 different methods can be compared. This paper reports the development of a system for the assessment of lameness in cows kept in tie-stalls (stall lameness score, **SLS**) and its validation by comparison with lameness identified by locomotion scoring using a published, repeatable method (Winckler and Willen, 2001).

MATERIALS AND METHODS

A veterinary surgeon with particular experience of husbandry, claw trimming, and treatment of tied cows (JH; observer A) identified a list of behavioral indicators that he associated with confined cows presenting foot lesions. These were regular, repeated shifting of weight from one foot to another; rotation of feet from the line parallel to the midline of the body; standing on the edge of a step; resting a foot (one foot more than another); and uneven weight bearing between feet when moving from side to side, demonstrated by more rapid movement by one foot to relieve another, or reluctance to bear weight on a particular foot. All these would be most likely to be detectable in the hind feet because of limited possibilities for observation and movement of the front feet. The indicators were discussed with 4 colleagues experienced in assessment of lameness by locomotion scoring and a protocol was developed on pilot visits to 6 farms (Leach et al., 2008). It was initially decided that at least 2 indicators should be required to classify the cow as lame, as it was expected that this would optimize the sensitivity (proportion of true positives correctly identified) and specificity (proportion of true negatives correctly identified) of the method. The procedure for assessment of cows tied in stalls was formalized as follows:

1. Any cows that were lying down were encouraged to rise and left for at least 3 min before being assessed.
2. Cows were examined individually from behind. First, the stance of the cow standing undisturbed in the stall was assessed, and presence of any of the indicators listed above was noted. The front feet were viewed as best possible, but it was often impossible to see them clearly.
3. The cow was then moved to left and right in the stall (by the assessor moving from side to side behind the animal, applying hand pressure to the hind quarters if necessary) and any reluctance to bear weight on a particular foot was noted. (Generally only the hind feet could be assessed in this case.)

Table 2. Contingency table for results of 2 observers classifying 98 cows as lame or not lame using the stall lameness score

	Observer A	
Observer B	Not lame	Lame
Not lame	69	5
Lame	2	22

4. The position resumed after movement was observed and any further indicators from the list noted.
5. If 2 or more indicators were recorded, the cow was scored as lame.

The method was tested by observer A and a second observer, B (SM), who was experienced in locomotion scoring but not with tied cows. The 2 observers visited 4 farms with a total of 98 cows. They scored the cows simultaneously in the stalls without consulting each other. The cows were then released one by one and observer B assigned each cow a locomotion score according to the 5-point scale of Winckler and Willen (2001) (Table 1). This scoring on the 5-point scale will be referred to as **WWLS**. For some analyses the categories were combined to give a binary locomotion score (**LS**) as follows: not lame (WWLS 1 or 2) or lame (WWLS 3, 4, or 5). A test of interobserver agreement for the SLS was carried out. The data collected were used to compare the detection of lameness using SLS and WWLS and investigate relationships between individual indicators observed in the stall and the locomotion score of the cow when released, thus testing the validity of the new method. The prevalence of lameness detected by SLS and binary LS was also compared. The implications of using the presence of different numbers of indicators to define lameness in the SLS were investigated retrospectively. The effect of using any single indicator with the exception of rotation was also investigated.

Statistical Analysis

The percentage agreement, kappa, and prevalence adjusted bias adjusted kappa (**PABAK**) statistics (Cohen, 1960; Byrt et al., 1993) were calculated for the SLS data collected by the 2 observers. The sensitivity and specificity of SLS, as a predictor of lameness according to binary LS, were calculated for each observer (Petrie and Watson, 1999).

The prevalence of lameness detected in each herd by each observer using SLS and by observer B using LS was calculated. The differences between these prevalences were expressed as percentages of the prevalence according to binary LS. The effects of farm and observer on this difference were analyzed by ANOVA.

The Chi-squared test was used to investigate whether there was a difference in the occurrence of the individual indicators used in the SLS between cows scored lame or not lame while walking.

RESULTS

Between-Observer Reliability for SLS

The classification of cows as lame or not lame by SLS by the 2 observers is summarized in Table 2. Percentage agreement between observers A and B was 91% (expected agreement 60.7%, kappa 0.81, PABAK 0.82).

Validity: Agreement Between SLS and Binary LS

Agreement between SLS and binary LS on classifying cows as lame or not lame was moderate to substantial, with 81% agreement for observer A (expected agreement 54.8%, kappa 0.58, PABAK 0.60) and 78% agreement for observer B (expected agreement 55.5%, kappa 0.50, PABAK 0.64). The WWLS data showed that the discrepancy between SLS and locomotion score was greatest in WWLS category 3 (mildly lame; Table 3). Observer A correctly identified 42% of these cows as lame by using SLS, whereas observer B detected only 26% of them. Among WWLS score 4 cows, observer A detected 71% and observer B detected 76% as lame when standing. All 3 cows that scored WWLS 5 were correctly identified as lame using the SLS by both observers.

Sensitivity and Specificity of the SLS and Effect of WWLS on Sensitivity

The SLS based on the presence of 2 indicators had a relatively low sensitivity for cows that were scored as lame when walking (Figure 1). Observer A identified 68% of cows that were recorded as lame when walking, whereas observer B identified only 54% of these. However, the test had very high specificity, meaning that it was very rare for a cow to be scored as lame in the stall when it had not been scored lame when walking. For observer B the specificity was 0.93; that is, 93% of the cows scored lame in the stall had been scored lame when walking. The specificity for observer A was even higher at 0.96. Cows suffering more severe lameness were easier to identify in the stall; sensitivity of SLS for detecting WWLS 4 and 5 was high at 0.9 for observer A and 0.8 for observer B.

Table 3. Percentage agreement between stall lameness score and locomotion score, by locomotion score category and observer

Gold standard 5-point locomotion score (observer B)		Cows correctly identified as lame or not lame when standing in the stall, %	
		Observer A	Observer B
1 (n = 1)	Not lame	100	100
2 (n = 57)	Not lame	93	93
3 (n = 17)	Lame	42	26
4 (n = 17)	Lame	71	76
5 (n = 3)	Lame	100	100

Individual Indicators

The Chi-squared test showed that resting a foot, weight shifting, and reluctance to bear weight all occurred significantly more often in cows that were scored lame when walking than in those that were not ($P < 0.001$). Standing on the edge of a step was the indicator least consistently recorded between observers, being recorded significantly more often in binary LS lame cows by observer A only. Rotation of the feet was equally likely to be recorded in cows that were scored as lame walking and those that were not.

Effect of Using a Single Indicator to Define Lameness in the SLS

In view of the above findings, the sensitivity and specificity of the SLS, using different threshold numbers of indicators (from 1 to 5) to define lameness, were calculated retrospectively from the data collected. Because the Chi-squared test had shown no significant difference in recording of rotation of the feet between lame and sound cows, the effect of using any single indicator with the exception of rotation [**SLS (1-R)**] was also investigated. The results are illustrated in a receiver operating characteristic curve in Figure 1. By definition, altering the threshold level of a test to make it more sensitive (i.e., to pick up more of the true positives) is likely to result in a loss of specificity (as the threshold is lowered, more false positives are likely to arise). The receiver operating characteristic curve is a common method of illustrating this trade-off. In this case, the threshold was lowered by reducing the number of indicators required to define a cow as lame. Figure 1 shows that a good combination of sensitivity and specificity, and close values for these characteristics between observers, would be achieved using SLS (1-R). However, if rotation is included as one of the possible single definitive indicators of lameness, the test has very low specificity (i.e., 40 to 50% of the animals scored as lame are false positives when compared with the results of locomotion scoring), whereas there is little loss of sensitivity (only 17 to 25% of cows that appeared lame when walking showed only rotation of the feet while standing).

Effects of Assessment Method on Estimation of Lameness Prevalence

The apparent prevalence of lameness on a farm based on SLS was lower than that based on binary LS (Table 4). The percentage underestimation ranged between 11 and 37% of the prevalence detected by LS (mean 26.9%, SD 8.87). Using SLS (1-R) (i.e., classifying the cow as lame if any one of the indicators on the original list was observed, with the exception of rotation of the feet) reduced the underestimation for 2 farms with observer A and for all farms with observer B. Analysis of variance showed that this underestimation was not significantly affected by farm or observer (Table 5).

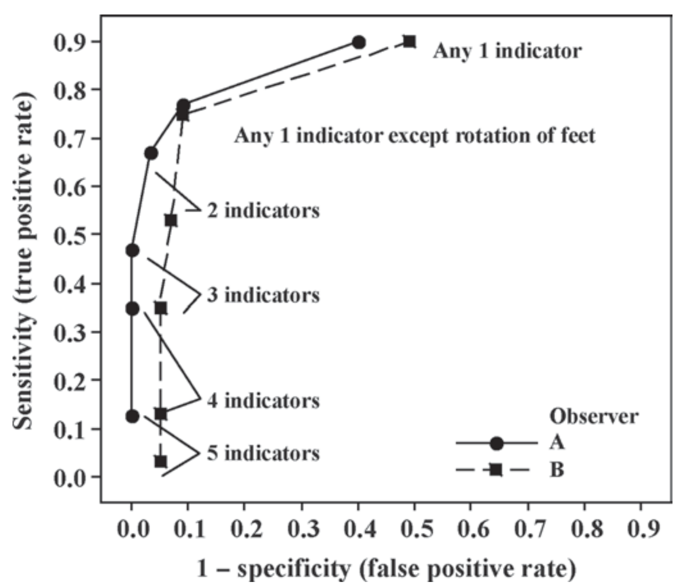

Figure 1. Receiver operating curves for stall lameness score for 2 observers with different threshold levels of indicators.

Table 4. Lameness prevalence detected on 4 farms by 2 observers using a variety of methods

Farm	Observer	Prevalence with binary locomotion scoring (LS)[1]	Prevalence with SLS[2]	Prevalence with SLS(1-R)[3]	Underestimation relative to LS using SLS, %	Underestimation relative to LS using SLS(1-R), %
1	A	62	48	48	23	23
	B	62	41	44	34	29
2	A	28	25	25	11	11
	B	28	18	21	36	25
3	A	35	25	29	29	17
	B	35	22	29	37	17
4	A	34	26	31	24	9
	B	34	27	31	21	9

[1]Locomotion scoring was carried out by observer B only.

[2]SLS = stall lameness score requiring presence of 2 indicators to define lameness.

[3]SLS (1-R) = SLS requiring presence of only 1 indicator to define lameness, with the exception of rotation of the feet.

DISCUSSION

Bearing in mind that the SLS method involves subjective assessment, agreement between the 2 observers was good (Fleiss et al., 2003). The observer less experienced with tied cows recorded only one indicator in some of the cows that were lame according to LS, and therefore, by the initial protocol, correctly classified fewer of the cows as lame (i.e., was less sensitive). This might be due to lack of experience in detecting some of the indicators. Sensitivity would be expected to increase with experience (March et al., 2007). Nevertheless, the effect of observer on the degree to which prevalence of lameness was underestimated by SLS compared with binary LS was not significant (Table 5).

Scoring cows in the stall did not detect all cows that were seen to be lame when walking. This may be inevitable in cases in which cows are able to maintain a comfortable posture when stationary but are forced to make painful movements to walk (only limited movement was made in the stall during the assessment). However, the more severe the lameness, the greater was the chance of detecting it in the stall.

The indicators initially suggested by the expert proved feasible to assess and are discussed in turn. Abnormal weight distribution and resultant postural changes, including lifting or rotating limbs, are commonly described in horses attempting to reduce limb pain (Ashley et al., 2005). Sound cows will stand with their weight distributed equally between feet, not favoring a foot for resting. Whay (2002) described deviation of the lame limb from the vertical (generally resulting from the cow placing one foot further cranially, caudally, medially, or laterally than the contra-lateral limb) or of the line between the tuber coxae from the horizontal, as indicators of lameness. These alterations in stance often occur in conjunction with resting a foot. Also, measurements using load cells have shown that lame cows place less weight on the lame leg and transfer weight to the contra-lateral leg (Rushen et al., 2006).

Weight shifting is the most commonly cited and reliable indicator of limb or foot pain in horses (Ashley et al., 2005). Load cells have shown that lame cows shift their weight more frequently from one foot to another compared with sound cows (Rushen et al., 2006) and observations of cows in the milking parlor by McMullan

Table 5. Analysis of variance of the underestimation of lameness prevalence using stall lameness score with 2 different thresholds compared with using locomotion score

Source	df	Sum of squares	Mean square	*F*	*P*-value
Underestimation using SLS[1]					
Farm	3	345.2	115.1	1.62	0.352
Observer	1	6.04	6.04	0.08	0.790
Error	3	213.8	71.26		
Total	7	565.1			
Underestimation using SLS(1-R)[2]					
Farm	3	193.8	64.6	3.15	0.186
Observer	1	156.5	156.6	7.64	0.070
Error	3	61.49	20.5		
Total	7	411.8			

[1]SLS = stall lameness score requiring presence of 2 indicators to define lameness.

[2]SLS (1-R) = stall lameness score requiring presence of only 1 indicator to define lameness, with the exception of rotation of the feet.

et al. (2006) indicated more shuffling and lifting of the feet in lame cows than in sound cows. In the present study, frequent weight shifting was more prevalent in lame cows than in nonlame cows. However, care should be taken to exclude movements caused by nervousness, flies, or anticipation of feeding or milking.

Prior personal experience (JH) revealed that a lame cow would often stand on the edge of a step to avoid bearing weight on a painful part of a foot. The feet of several of the cows observed to stand in this way were lifted for examination and were found to have sole ulcers. The stance adopted is likely to have relieved pressure on the ulcer site. This stance was often combined with outward rotation of the foot, so that the inner claw would bear most of the weight. However, if a large number of cows in a herd are standing on the edge of a step, the cause could be stall design. Cows tied in stalls that are too short for them may be forced to stand on the edge of the raised bed.

Sound animals will transfer weight from one foot to another with smooth, even movements and without hesitation. Reluctance to bear weight on a particular foot, creating a limp, is a generally accepted visible sign of lameness in moving animals. Moving the cow from side to side in the stall was used to try to detect this. It was expected that reluctance to bear weight would be an obvious indicator in a lame tied cow. However, it was only recorded in 40% of cows considered lame by locomotion scoring and 60 to 70% (depending on observer) of cows scored as lame in the stall. Limitations to movement in the stall may make this indicator less apparent. In particular, the movement of the front feet is minimal, which is a limitation of the method, as front limb lameness may be overlooked. In fact, in this study, front leg lameness did not play a major role. Had there been more front leg lameness, agreement between SLS and binary LS might not have been as high. Swollen carpal joints are quite common in tied cows because of poor stall design. The lameness assessment could be combined with an assessment of visible swellings and lesions to account for these abnormalities.

The least reliable indicator of lameness observed when walking was rotation of the feet. Zurbrigg et al. (2005) used hind claws rotated outwards (more than 20° from the cow's midline) as 1 of 2 indicators of lameness in tied cows, reporting a mean prevalence of 23% foot rotation in 317 herds. However, no validation of these indicators was presented. More recently, Cramer (2008) found that foot rotation had a poor relationship with presence of lesions and its specificity was variable between observers. In the present study, rotation of the feet alone was not exclusively associated with lameness, with many cows demonstrating rotation but sound locomotion. This might occur because the rotation is a compensatory action that prevents painful areas of the foot from bearing weight. Alternatively, rotation may be associated with the early stages of lesion or lameness development and, in fact, be a more sensitive indicator of foot problems than locomotion scoring. Further investigations are necessary to explore this. Possible alternative reasons for rotation of the feet include overgrown claws, poor conformation, or a large udder.

In general, it was found that the number of indicators recorded increased with the severity of lameness. The specificity of using any single indicator to define lameness in the standing cow was checked and found to be low and variable between observers. However, it was greatly increased by excluding positives defined by rotation alone [(SLS (1-R)], as foot rotation was commonly recorded in nonlame cows. Retrospectively, it was shown that sensitivity could be increased with a moderate loss of specificity by using SLS (1-R), and the sensitivity and specificity of the 2 observers were closest with this method. As always with conflict between sensitivity and specificity, the optimum decision depends on the purpose of the test. For use in welfare assessment, specificity is important to avoid unduly harsh judgment. However, for management purposes, examining the feet of cows with a single indicator, even including rotation, may be rewarding, because some of these cows will be lame and some may have early-stage lesions and benefit from treatment. Further investigations using the SLS and including claw examinations would be revealing.

The method developed can be carried out with relatively little disturbance to the cattle or the farmer. Moving the cows from side to side can generally be achieved quite easily, often merely by stepping from side to side behind the cow, as she will tend to move to keep the observer in view. In some cases some hand pressure on the hind quarters may be necessary to initiate movement. Care should be taken that the underfoot surface is not dangerously slippery for the cow. Assessment should not be made while a cow is being milked, as this would be disturbing, and the cow's stance and behavior may be affected by the milking process.

Although developed by researchers, this method of identifying lame cows could be of use in practical management to help farmers and their advisers identify cows requiring treatment, as well as for welfare assessment. Standardization might be more difficult to achieve across this large and varied population, but in this case standardization would be less important as the main objective would be to improve the lameness detection on each individual farm from its current state, to allow more prompt treatment. Some of the indicators might even be helpful in free-stall systems; for example, when observing cows at the feed rail, although their use in this setting was not evaluated.

CONCLUSIONS

The method developed is considered feasible and valid for detecting lame cows in tie-stalls, although it will not be as sensitive as locomotion scoring of freely moving animals. Therefore, locomotion scoring remains the preferred option where it is possible, but this method provides an alternative. For welfare assessment, where it is important to avoid unduly harsh judgment, we recommend that either at least 2 of the specified indicators should be present to determine that a cow is lame, or rotation is excluded but presence of any one of the remaining indicators is used to define lameness. However, if the objective is to identify all cows with potential problems, then rotation of the feet could be included and single indicators used. This small-scale study suggests that the degree of underestimation of lameness prevalence that occurs when using the SLS is relatively consistent between farms and observers, but a larger scale investigation on more farms is needed to explore this relationship further. Problems do remain with making an entirely fair comparison of lameness prevalence between tied herds and loose-housed herds.

ACKNOWLEDGMENTS

We are grateful to all the farmers who gave us access to their cows and to Christine Leeb (University of Veterinary Medicine, Vienna, Austria) and Herbert Strnad for valuable input to the initial discussions. This study was part of the Welfare Quality® research project that has been co-financed by the European Commission, within the 6th Framework Programme (contract no. FOOD-CT-2004–506508). The text represents the authors' views and does not necessarily represent a position of the Commission, who will not be liable for the use made of such information.

REFERENCES

Ashley, F. H., A. E. Waterman-Pearson, and H. R. Whay. 2005. Behavioural assessment of pain in horses and donkeys: Application to clinical practice and future studies. Equine Vet. J. 37:565–575.

Bielfeldt, J. C., R. Badertscher, K. H. Tolle, and J. Krieter. 2005. Risk factors influencing lameness and claw disorders in dairy cows. Livest. Prod. Sci. 95:265–271.

BMLFUW. 2007. Grüner Bericht 2007. Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft, Vienna, Austria.

Byrt, T., J. Bishop, and J. B. Carlin. 1993. Bias, prevalence and kappa. J. Clin. Epidemiol. 46:423–429.

CanWest DHI. 2007. 2006 Ontario DHI Progress Report. CanWest DHI, Guelph, Ontario, Canada.

Cohen, J. 1960. A coefficient of agreement for nominal scales. Educ. Psychol. Meas. 20:37–46.

Cook, N. B. 2003. Prevalence of lameness among dairy cattle in Wisconsin as a function of housing type and stall surface. J. Am. Vet. Med. Assoc. 223:1324–1328.

Cramer, G. 2008. The relationship between lameness scores and productivity in Ontario dairy cattle. Pages 444–449 in Proc. 15th Symp. 7th Int. Conf. Lameness in Ruminants, Kuopio, Finland. Savonia University of Applied Sciences, Kuopio, Finland.

Espejo, L. A., M. I. Endres, and J. A. Salfer. 2006. Prevalence of lameness in high-producing Holstein cows housed in freestall barns in Minnesota. J. Dairy Sci. 89:3052–3058.

Fjeldaas, T., A. M. Sogstad, and O. Østeras. 2006. Claw trimming routines in relation to claw lesions, claw shape and lameness in Norwegian dairy herds housed in tie stalls and free stalls. Prev. Vet. Med. 73:255–271.

Fleiss, J. L., B. Levin, and M. C. Paik. 2003. Statistical Methods for Rates and Proportions. 3rd ed. John Wiley and Sons, New York, NY.

Hassall, S. A., W. R. Ward, and R. D. Murray. 1993. Effects of lameness on the behaviour of cows during the summer. Vet. Rec. 132:578–580.

Kujala, M., M. Pastell, and T. Soveri. 2008. Use of force sensors to detect and analyse lameness in dairy cows. Vet. Rec. 162:365–368.

Leach, K. A., J. Huber, H. R. Whay, C. Winckler, S. March, and S. Dippel. 2008. Assessing lameness in tied cows. Pages 126–128 in Proc. 15th Symp. 7th Int. Conf. Lameness in Ruminants, Kuopio, Finland. Savonia University of Applied Sciences, Kuopio, Finland.

Loberg, J., E. Telezhenko, C. Bergsten, and L. Lidfors. 2004. Behaviour and claw health in tied dairy cows with varying access to exercise in an outdoor paddock. Appl. Anim. Behav. Sci. 89:1–16.

Manske, T., J. Hultgren, and C. Bergsten. 2002. Prevalence and interrelationships of hoof lesions and lameness in Swedish dairy cows. Prev. Vet. Med. 54:247–263.

Manson, F. J., and J. D. Leaver. 1988. The influence of concentrate amount on locomotion and clinical lameness in dairy cattle. Anim. Prod. 47:185–190.

March, S. 2004. Tierhaltung. In Bundesweite Erhebung und Analyse der verbreiteten Produktionsverfahren, der realisierten Vermarktungswege und der wirtschaftlichen sowie sozialen Lage ökologisch wirtschaftender Betriebe und Aufbau eines bundesweiten Praxis-Forschungs-Netzes. G. Rahmann, H. Nieberg, S. Drengemann, A. Fenneker, S. March, and C. Zurek, ed. Landbauforschung-Völkenrode Sonderheft 276:93. Braunschweig, Germany.

March, S., J. Brinkmann, and C. Winkler. 2007. Effect of training on the inter-observer reliability of lameness scoring in dairy cattle. Anim. Welf. 16:131–133.

McMullan, A. J., M. E. Scott, C. J. Nicol, A. M. Nolan, J. L. Fitzpatrick, and B. Lucas. 2006. Associations between behavioural indicators and inflammatory disease in dairy cows. Page 55 in Proc. 40th Int. Congr. ISAE, Bristol, UK.

Petrie, A., and P. Watson. 1999. Statistics for Veterinary and Animal Science. Blackwell Science, Oxford, UK.

Regula, G., J. Danuser, B. Spycher, and B. Wechsler. 2004. Health and welfare of dairy cows in different husbandry systems in Switzerland. Prev. Vet. Med. 66:247–264.

Rushen, J., E. Pombourcq, and A. M. De Passillé. 2006. Local anaesthetic as a means to validate measures of lameness in dairy cows. Page 53 in Proc. 40th Int. Congr. ISAE, Bristol, UK.

Singh, S. S., W. R. Ward, K. Lautenbach, and R. D. Murray. 1993. Behaviour of lame and normal dairy cows in cubicles and in a straw yard. Vet. Rec. 133:204–208.

Sogstad, A. M., T. Fjeldaas, O. Østeras, and K. P. Forshell. 2005. Prevalence of claw lesions in Norwegian dairy cattle housed in tie stalls and free stalls. Prev. Vet. Med. 70:191–209.

Sprecher, D. J., D. E. Hostetler, and J. B. Kaneene. 1997. A lameness scoring system that uses posture and gait to predict dairy cattle reproductive performance. Theriogenology 47:1179–1187.
Whay, H. R. 2002. Locomotion scoring and lameness detection in dairy cattle. In Practice 24:444–449.
Whay, H. R., D. C. J. Main, L. E. Green, and A. J. F. Webster. 2003. Assessment of the welfare of dairy cattle using animal-based measurements: Direct observations and investigation of farm records. Vet. Rec. 153:197–202.
Whay, H. R., A. E. Waterman, and A. J. F. Webster. 1997. Associations between locomotion, claw lesions and nociceptive threshold in dairy heifers during the peri-partum period. Vet. J. 154:155–161.
Whay, H. R., A. E. Waterman-Pearson, and A. J. F. Webster. 2002. The use of behavioural observation in the identification and monitoring of lameness. Pages 302–305 in Proc. 12th Int. Symp. Lameness in Ruminants, Orlando, FL.
Winckler, C., and G. Brill. 2004. Lameness prevalence and behavioural traits in cubicle housed dairy herds—A field study. Pages 160–161 in Proc. 13th Int. Symp. Conf. on Lameness in Ruminants, Maribor, Slovenia. Univerzitetna Knjižnica Maribor, Maribor, Slovenia.
Winckler, C., and S. Willen. 2001. The reliability and repeatability of a lameness scoring system for use as an indicator of welfare in dairy cattle. Acta Agric. Scand. Anim. Sci. Suppl. 30:103–107.
Zurbrigg, K., D. Kelton, N. Anderson, and S. Millman. 2005. Tie-stall design and its relationship to lameness, injury and cleanliness on 317 Ontario dairy farms. J. Dairy Sci. 88:3201–3210.