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Original Article

Optimising lameness detection in dairy cattle by using handheld infrared thermometers

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Abstract

Lameness is one of the most serious economic and welfare issues in the dairy industry. Early detection of lameness can be difficult, but provision of early treatment is crucial. Previous studies have used infrared thermography to show that increased foot temperature (FT) is associated with lameness and foot lesions. However, poor accuracy has limited the management application potential. This study analysed ambient-temperature (AT)-adjusted foot-surface temperatures and temperature differences between the hind feet of individual cows to enhance lameness detection. Cow FTs were recorded on a 990-cow farm using an infrared thermometer fortnightly for 6 months. Additionally, mobility level was scored using the AHDB Dairy 4-point scale. The averages of FTs and ATs were 23.83 ± 0.03°C and 13.99 ± 1.60°C, respectively. The FT of cows with lameness was significantly higher than that of cows without lameness ($P < 0.001$). Increases in FTs correlated with the mobility score (MS) ($P < 0.001$). According to receiver operating characteristic (ROC) curves, the optimal threshold based on actual FTs was 23.3°C with 78.5% sensitivity and 39.2% specificity. However, the ROC curve for the AT-adjusted FT and FT difference parameters showed minimal improvements over the FT in detecting lameness. In conclusion, the infrared thermometer results demonstrated the association between elevated FTs and lameness, but further improvements to this detection technique will be required before it can be implemented as a management tool for detecting cows that could benefit from treatment. With additional validation, the technique could be used as a screening device to identify cows in need of further assessment.

Keywords: animal welfare, cattle, lameness.

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Introduction

Lameness is one of the most serious economic and welfare issues in the dairy industry because it not only reduces mobility but also can cause pain in animals (Whay *et al.* 1998) and is associated with poor body condition (Randall *et al.* 2015). In addition, Cha *et al.* (2010) found that lameness causes financial losses range from US$ 120 to US$ 215 per case. These losses are primarily due to veterinary costs (Cha *et al.* 2010), decreased milk yield (Green *et al.* 2002; Randall *et al.* 2016), a reduced fertility rate (Melendez *et al.* 2003) and an increased culling rate (Esslemont & Kossaibati 1997; Booth *et al.* 2004; Olechnowicz & Jaskowski 2011).

Lameness is usually caused by pain in the limb, as an animal tends to shift its weight to reduce the weight load on the affected limb (Neveux *et al.* 2006). A recent estimate showed that lameness prevalence in the United Kingdom is approximately 36% (Barker *et al.* 2010). The majority of lameness cases are associated with foot lesions (O'Callaghan 2002). Hedges *et al.* (2001) reported sole ulcers, white line disease, digital dermatitis and interdigital necrobacillosis as the 4 most frequently occurring lesion types that cause lameness in cattle. Murray *et al.* (1996) confirmed that 92% of foot lesions occur in the hindlimbs.

Traditionally, lameness detection relies on visual assessment by stockpeople. Treatment for lame cows can be initiated only after a stockperson has recognised the relevant signs. Previous studies have shown that farmers have difficulty detecting lameness early and often underestimate its prevalence (Whay *et al.* 2003; Archer *et al.* 2010; Sárová *et al.* 2011). Early treatment for lameness may reduce pain and greater chances of recovery, thereby restoring their economic value (Leach *et al.* 2012). Locomotion assessments can effectively identify lameness and the severity of lesions (Whay *et al.* 1997) are commonly used in commercial farm settings. However, such assessments have limitations, for example, assessors are required to be trained frequently to maintain assessment consistency (Whay 2002). In this study, the focus on foot temperature (FT) as an indicator of lameness is supported by evidence of foot lesions being a major cause of lameness in dairy cattle (Murray *et al.* 1996). Although foot lesions might not be the sole cause of lameness, Whay *et al.* (1997) reported a significant correlation between lesion severity and mobility impairment.

In recent years, infrared thermography has been suggested as a non-invasive diagnostic tool (Stewart *et al.* 2005) that indirectly measures blood flow changes by detecting minor changes in skin temperature associated with inflammation from foot lesions. Therefore, infrared thermography may be a helpful technique for detecting lameness on farms (Alsaaod & Buscher 2012; Main *et al.* 2012; Stokes *et al.* 2012a,b).

Thermography has been studied for its clinical use in inflammation diagnoses over the past two decades (Turner 1991). Many studies have focused on diagnosing lameness in horses (Fonseca *et al.* 2006; Toth 2006; Soroko & Jodkowska 2011; Cetinkaya & Demirutku 2012), and thermography is considered a valuable clinical tool for the rapid identification of equine distal limb inflammation and lameness (Levet *et al.* 2009).

Infrared thermographic cameras are expensive. By contrast, infrared thermometers are less expensive, portable and easy to use and, thus, may be a suitable alternative for farmers (Main *et al.* 2012). However, some studies have reported, for example, ambient temperatures (ATs) and animal activity immediately prior to measurement may affect repeatability (Stewart *et al.* 2005; Gloster *et al.* 2011). To evaluate whether the AT would affect the accuracy of lameness detection by thermometer, the present study explored the value of analysing AT-adjusted foot-surface temperatures and temperature differences between hind feet to enhance the effectiveness of lameness identification.

Materials and methods

This study was conducted from February to July 2012 on a dairy farm containing 990 cows, the majority of which were Holsteins. The cows were milked three times a day and data were collected during the afternoon milking session between 13:30 and 16:00 fortnightly for 22 weeks. Upon entering the milking parlour, cold water from the mains supply was sprayed on to the cows' feet to clean them. After the milking clusters had been attached, hind FTs were measured using a non-contact infrared thermometer with dual-laser targeting (product code: N85FR; Maplin Electronics, Manvers, Rotherham, UK) and a reported accuracy ±0.1°C and a distance-to-spot-size ratio of 12:1. To measure a cow's FT, the infrared thermometer scanned the area indicated in Fig. 1 (Main *et al.* 2012), and as suggested by Hanley & McNeil (1982). An automatic data holding enabled data to be saved when measuring the area, and the maximum temperature was displayed. Due to the time limits, each area was scanned once and the highest left and right hind FTs in the scanned area were recorded. The AT outside the parlour was recorded at the start of each milking session by using a Kestrel® 4000 Pocket Weather Meter (Nielsen-Kellerman, Boothwyn, PA, USA) with a reported accuracy of ±1.0°C. In addition, cows were scored in mobility near the parlour exit with the AHDB Dairy (formally known as DairyCo.) 4-point scale (0, 1, 2 and 3) (DairyCo, 2009) by the same trained assessor working for a veterinary practice. The assessor and the observer conducting the thermography were blind to each other's scores.

Statistical analysis

The data were analysed using IBM SPSS Statistics for Windows, Version 19.0 (released 2010; IBM

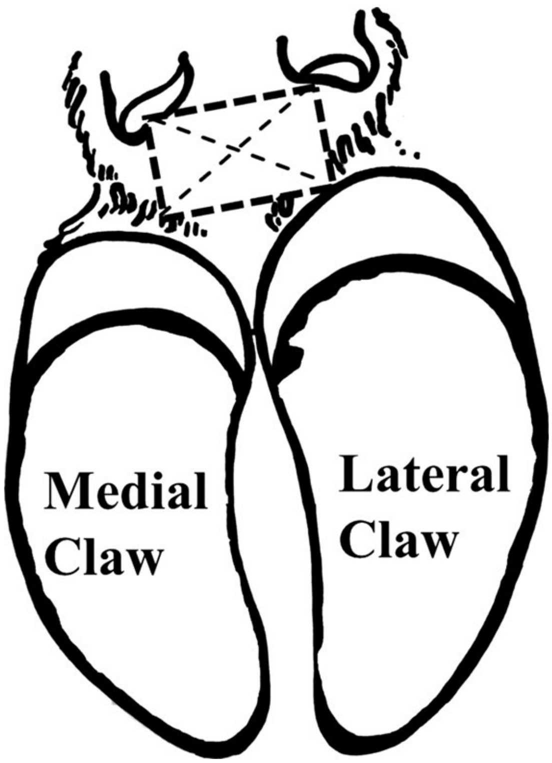

Fig. 1 Infrared thermometer scan of the area indicated in red and the maximum temperature recorded (Main *et al.* 2012).

Corp., Armonk, NY, USA). Pearson correlations and regression were used to analyse the association between AT and maximum FT, and between AT and temperature difference between left and right hind feet (FTD). Spearman's correlation was performed to analyse the association between MS and FT or FTD. A *t* test was performed to compare continuous FT and FTD data and categorical data (lame: MS = 2 or 3; not lame: MS = 0 or 1).

A simple linear regression was conducted to create a model to adjust the AT by comparing the AT with the FT data of cows without lameness (MS = 0). Subsequently, FTs were adjusted based on this model and a new variable, adjusted FT (AFT), was defined. Furthermore, a receiver operating characteristic (ROC) curve was used to test various FT models for identifying no lameness (MS = 0 or 1) or lameness (MS = 2 or 3). Sensitivity, specificity, positive predictive values, negative predictive values and areas under the ROC curves for each predictive variable were compared. For all analyses, a two-tailed $P < 0.05$ was considered statistically significant. Analysis was performed using MedCalc for Windows Version 12.7.2 (released 2013; MedCalc, Ostend, Belgium).

Results

A total of 11 890 observations of cows were recorded. The AT ranged from 6 to 23°C with an average of 13.83 ± 5.70°C (mean ± standard deviation). The FT ranged from 7 to 32°C (Table 1).

The raw data were tested for normality. The residuals of this large data set only slightly deviated from the P-P plot, and thus transforming the data was deemed unnecessary (data not shown).

In this study, the percentage of cows with MSs of three from any of the 12 visits ranged from 0% (from a total of five visits) to 0.3%. Only 16 cases received an MS of 3; hence, these cases were combined with those with MSs of 2.

Figure 2 shows no overlap between the 95% confidence intervals of the FT for each of the three MSs or between the 95% confidence intervals of the FT for cows with lameness (MS = 2 or 3) and no lameness (MS = 0 or 1).

Furthermore, Spearman's rank-order correlation coefficient showed that the FT increased in correlation with the MS ($P < 0.001$). In addition, the *t*-test results showed that the FT of cows with lameness was significantly higher than that of cows which were not lame ($P < 0.001$).

Although no significant correlation was found between the FTD and MS, the *t*-test results showed that the FTD was significantly larger when at least one foot was lame than when no feet were lame ($P < 0.001$). Figure 3 illustrates that the 95% confidence interval of the FTD of cows without lameness did not overlap with that of cows with lameness.

Figure 4 illustrates a positive correlation between FT and AT ($r = 0.402$, $P < 0.001$) and a negative correlation between FTDs at various ATs ($r = -0.223$, $P = 0.001$). Because of the identical ATs at the third and sixth visits and fifth and seventh visits, the data in Fig. 4 overlap.

Table 1. MSs, ambient temperatures and foot temperatures from 11 890 observations of cows assessed on 12 farm visits

Visit	1	2	3	4	5	6	7	8	9	10	11	12
Ambient temperature	6.0	7.0	12.0	13.0	10.0	12.0	10.0	21.6	14.4	21.3	17.9	23.0
MS 0 (%)	63	66	69	69	66	62	58	58	59	57	61	55
MS 1 (%)	32	30	27	27	30	34	37	37	36	38	35	40
MS 2 + 3 (%)	4	4	4	4	3	4	5	5	5	5	4	6
Foot temperature of MS 0 cows (°C)												
Mean	22.3	21.5	23.6	24.7	23.0	22.4	22.8	25.9	22.5	25.3	24.7	25.9
SD	3.9	3.9	3.2	2.8	3.3	3.1	3.0	2.0	2.3	1.7	2.2	1.9
Foot temperature of MS 1 cows (°C)												
Mean	23.3	22.2	24.1	25.1	23.4	22.5	22.9	26.1	22.8	25.2	24.9	26.2
SD	3.4	3.5	2.8	2.7	3.0	2.9	2.9	1.8	2.2	1.9	2.4	1.7
Foot temperature of MS 2 + 3 cows (°C)												
Mean	23.8	22.9	25.2	26.1	25.5	23.6	23.4	26.6	24.0	25.6	25.4	26.9
SD	3.0	3.1	2.4	2.7	2.0	1.8	2.7	1.5	1.9	1.8	2.2	1.5

MS, mobility score.

A regression analysis was used to incorporate the assumption that AT exerted a simple linear effect on FT. To create a prediction model, only the FTs of cows with MSs of 0 were used. The results were expressed as follows:

$$\text{Maximum foot temperature} = 20.354 + 0.241 \times (\text{ambient temperature}).$$

The regression coefficient was statistically significant ($P < 0.001$). This result was applied to adjust the FT to create the AFT variable.

The thermal data were used to establish thresholds above which a cow is classified as lame. The ROC curve can be used to determine the optimal threshold for classifying a cow as lame and the associated sensitivity and specificity of that threshold. Table 2 shows the results from three ROC curves used to detect lameness. The results suggest that the optimal FT value for classifying a cow as lame was 23.3°C, which exhibited a sensitivity of 78.5% and a specificity of 39.2%. The optimal AFT threshold value for lameness identification was 22.9°C, which exhibited a sensitivity of 71.5% and a specificity of 47.3%. Finally, the optimal FTD threshold for classifying a cow as lame was 0.8°C, which exhibited a sensitivity of 63.9% and a specificity of 47.1%. These three variables all had high negative predictive values but low positive predictive values at the cutoff points.

Discussion

The results of this study show that the FT assessed using the infrared thermometer was strongly associated with the MS, with cows with lameness exhibiting higher FTs than those without lameness. This finding supports those of Main *et al.* (2012), which showed that a handheld infrared thermometer can detect FT variations. In addition, the results of the present study are similar to those of Stokes *et al.* (2012a), who used a thermographic camera to detect whether FTs were elevated in feet with lesions.

Despite significant differences between the FTs of cows with and those without lameness, infrared thermometers were not highly effective for detecting lameness in individual cows. All three variables tested (FT, FTD and AFT) were relatively poor in lameness discrimination (Castro *et al.* 2011). The areas under the curves of these three variables were similar, with the AFT exhibiting slightly higher accuracy. The relationship between predictive values was improved for the AFT (Table 2). The high negative predictive values and low positive predictive values show that these variables might be more effective for ruling out lameness. Similar to airport thermal screening of passengers for fever (Chiang *et al.* 2008), infrared thermography has the potential for application as a thermal scanning method to rule out cattle without lameness. A further validation method

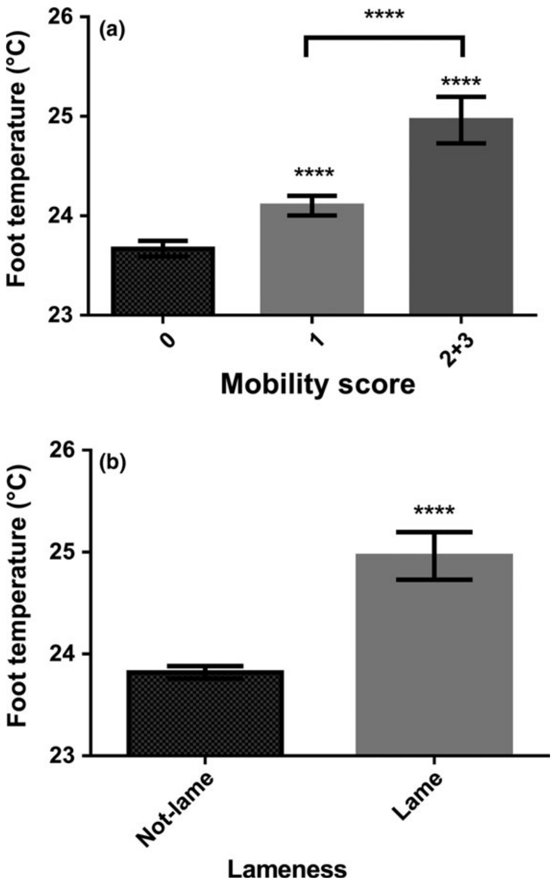

Fig. 2 Mean foot temperatures (°C) (FT) with 95% confidence intervals for each mobility score (a) and cows with and without lameness (b). Asterisks indicate statistical significance (****$P < 0.0001$).

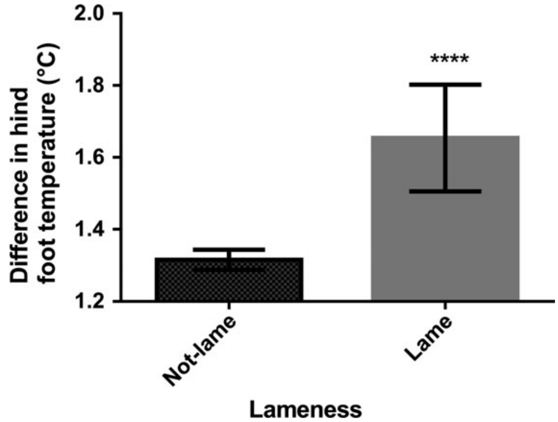

Fig. 3 Means and 95% confidence intervals of the difference in temperature between left and right hind feet (FTD) for cows without lameness (mobility score = 0 or 1) and with lameness (mobility score = 2 or 3). Asterisks indicate statistical significance (****$P < 0.0001$).

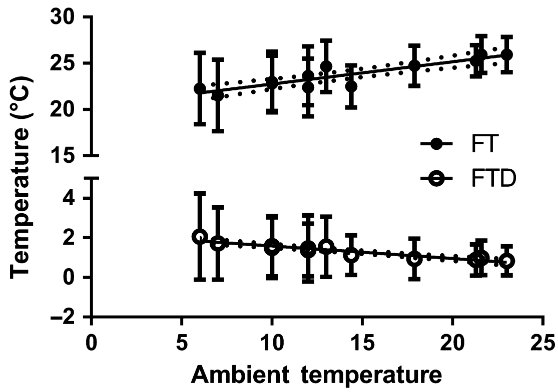

Fig. 4 Relationships of ambient temperature with foot temperature (FT) and the difference in temperature between left and right hind feet (FTD).

should be applied because lameness prevalence in this study was below the national average in the United Kingdom (Archer *et al.* 2010; Barker *et al.* 2010).

One study reported that activity prior to measurement might affect FT (Gloster *et al.* 2011). However, in the current study, all the cows were waiting in the collecting yard before entering the rotating parlour, and activity levels were not expected to vary significantly between cows.

A possible explanation for inadequate lameness detection in individual cows is that an animal's FT is influenced not only by the AT but also by the animal's lactation stage (Nikkhah *et al.* 2005). Nikkhah *et al.* (2005) verified that FTs were higher in cows in the early and middle lactation stages than in those in the late stages. However, lactation stages were not recorded in the current study.

Nevertheless, it remains possible that the thermometer is in fact a useful device in screening lameness cases. Based on our results, the improvement of the AT-adjusted model in detecting lameness was not as expected. However, the unexpected results might due to the inherent limitations of MS. In the following paragraphs, we provide further discussion to this matter.

One explanation might be that the sensitivity of MS, whether it is adequate to detect the foot

Table 2. Optimal threshold values for hind foot temperature in cows with each variable determined through receiver operating characteristic curve analysis

Variable	Threshold value (°C)	Sensitivity (%)	Specificity (%)	AUC	*P*-value	PPV	NPV
FT	>23.3	78.5	39.2	0.61	<0.0001	5.77	97.46
AFT	>22.88	71.5	47.3	0.613	<0.0001	6.05	97.22
FTD	>0.8	63.9	47.1	0.569	<0.0001	5.42	96.49

AFT, adjusted foot temperature; FT, foot temperature; FTD, temperature difference between left and right hind feet; NPV, negative predictive value; PPV, positive predictive value.

inflammation. The mobility scoring system is a method to categorise the gait of animals into subsets (Manson & Leaver 1988). Flower & Weary (2006) suggested that the numerical gait rating system was able to achieve 92% of accuracy in classifying sole ulcers. However, it was not as ideal in the other hoof pathologies. Consequently, high feet temperature might be observed with high MS.

An animal tends to shift the weight load from a painful limb to the other limbs. As the result, an uneven gait to obvious limping would present when a cow walks based on the severity of lameness. However, when either bilateral or all feet were affected by lameness, it was not likely to show a change in weight distribution (Neveux *et al.* 2006). A cow might show high FTs which are not necessarily reflected in the MS. Unfortunately, the information on specifying the lame limb of each cow was not available in this study. This limited the study of discovering the difference between the temperature difference of right and left foot and the associating with MS.

Moreover, the subjectivity and repeatability of the MS is often a concern of the accuracy to identify lameness (Archer *et al.* 2010). O'Callaghan *et al.* (2003) reported a 72% of intra-observer repeatability and 30% of inter-observer agreement in locomotion scoring system. Moderate intra- and inter-observer agreement were also reported in the study by Thomsen *et al.* (2008) with kappa value range from 0.43 to 0.60 and 0.32 to 0.52, respectively. Although the same MS was used throughout the study, there still might be a degree of inconsistency in the mobility scoring process due to lack of a gold standard for further confirmation. Evidently, the visual locomotion scoring system is far from perfect in identifying foot inflammation. Lesion score, on the other hand, might provide a superior discrimination of foot disorder (Wood *et al.* 2015).

Furthermore, inflammation at the study area is not the only the cause of uneven locomotion. First, several cases of arthritis were found in the study by Dyer *et al.* (2007) which showed clear visible locomotion disturbances with absence of claw lesion. In this case, the MS would indicate lame, but it would not reflect on the FT.

One more thing need to be taken into account is the chronic and acute phases of lameness. The study by O'Callaghan *et al.* (2003) demonstrated that the chronic foot lesions were likely to be related to higher locomotion score than acute foot lesions. In contrast, the acute inflammation is usually characterised with increase in local temperature, whereas the chronic inflammation is normally accompanied by the absence of fever (Horadagoda *et al.* 1999). In that case, increase in FT might not accurately correspond to high MS.

Lastly, inherited lameness might also affect the results. However, this was not considered in this study because lameness was virtually non-heritable (Boelling & Pollott 1998).

With various management approaches in dairy farms, the temperature threshold indicating lameness might not be uniform across all farms. For example, on the farm in this study, a small amount of water was sprinkled on the cows' feet, contributing to an FT threshold for identifying lameness of approximately 23.9°C, which is 1.35°C lower than the threshold in Main *et al.* (2012). In addition, Stokes *et al.* (2012a) suggested that moisture provides a cooling effect that can lower FT by up to 5°C. Therefore, the results should be interpreted carefully and further research is required for confirmation of the water effect on the lame FT.

The data obtained in this study were collected from one dairy farm in the southwestern United Kingdom and, thus, might not be representative of the entire dairy industry. The advantage of this study was the large quantity of samples collected. The size of the farm (990 cows) in this study is large compared with the national average, which was approximately 123 heads per herd in 2011 (DairyCo, 2013). In contrast to our initial expectations, the lameness prevalence rate was approximately 5%, which is considerably lower than the national average of almost 37% (Barker *et al.* 2010), the drawback being an insufficient quantity of cows with MSs of 3 for statistical evaluation.

A handheld thermometer is a simple tool for measuring FT that requires minimal training to use. In addition, data obtained using a handheld thermometer are unaffected by the perception or skill level of the assessors. Although this study was unable to achieve high levels of accuracy in predicting lameness in individual cows, a high-risk group was identified for further assessment. Moreover, the technique proposed in this study could serve as a tool for ranking farms according to lameness prevalence once the relevant factors have been adjusted. Further study is required to validate this method as an effective onsite lameness detection tool for cattle herds.

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Conflicts of interest

The authors declare that they have no conflict of interest.

Ethics statement

The authors confirm that the ethical policies of the journal, as noted on the journal's author guidelines page, have been adhered to. No ethical approval was required as non-invasive procedure was carried out in this study.

Contributions

YL collected and analyzed the data and provided an initial draft of the manuscript. SM helped to draft and critically revise the manuscript. DCJM designed and supervised the study. All authors reviewed and agreed the content of the final manuscript.

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