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Validation and Comparison of Two Different Pedometers that Could be Used for Automatic Lameness Detection in Dairy Cows

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Lameness in dairy cows causes significant losses in dairy production and is an important animal welfare issue. The overall size increase of dairy establishments and the subjectivity of lameness scoring mean that farmers possibly recognise only a relatively small percentage of lame animals in their herd. Lameness recognition is often only recognised when the underlying pathological process is already well advanced, causing higher veterinary treatment costs, loss of milk yield and pain for the animal.
The purpose of a current project at the Bavarian State Research Centre for Agriculture, Germany is to expand on the results of a previous project, which demonstrated that the association between various automatically recorded performance and activity parameters could be used to detect lameness in dairy cattle. The pedometers ("Track a Cow", ENGS Corporation, Israel) used in said project are able to measure lying behaviour through accelerometers and feeding behaviour by identifying cows at the feeding bins by way of an induction loop. The same pedometers have recently been updated and are to be used in the current project. Therefore the technology's reliability and validity will be evaluated.
At the same time as the validation the data collected by the ENGS "Track a Cow" ("TAC") pedometers will be compared to that collected by the more cost intensive "ALT" (Activity-Lying-Temperature, IBS Ing.Büro Schleusener, Mixdorf, Germany) tags which have been used successfully for many years, in order to evaluate the cost-benefit ratio of both devices.

1. Introduction

1.1 Impact of lameness in dairy farming

Because of both its economic relevance and impact on animal welfare (Whay et al., 2003), lameness in cattle remains very significant as a subject of research in the field of dairy farming. It is a cause of pain for cows and results in economic loss due to reduced reproductive efficiency, reduced milk production and cost of treatment (Archer et al., 2010; Bruijnis et al., 2010; Green et al., 2010).
Because of the increasing size of dairy farms, direct observation of animals in the barn becomes more arduous. Studies have shown that farmers significantly underestimate the lameness prevalence within their herds (Whay et al., 2002, 2003). In a study by Šárová et al. (2011), farm managers' estimation of lameness prevalence within their herd was lower than that determined by trained observers. All farmers involved in the study underestimated the level of lameness, with the average estimate approximately five times lower than the observed prevalence. The difference in estimation of lameness prevalence between trained observers and farmers scoring their own herd shows that there is a need for technologies that help farmers identify lame animals earlier and more efficiently (Pastell and Madsen, 2008).

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1.2 The use of accelerometers for lameness detection

Pastell et al first used accelerometers in 2009 to detect lameness in dairy cows (Pastell et al., 2009). A study by Mangweth et al. (2011) showed that acceleration measured using a three dimensional accelerometer placed between the Tuber coxae on the animals' back could be employed in a prediction model for lameness detection. The prediction model correctly predicted 94 % of lame cows and 80 % of sound cows. Though the study shows the validity of using sensors for lameness detection, it still remains a method confined to use in research due to the equipment used, which could constrict cows in their natural gait pattern and behaviour and thus isn't suitable for everyday use (Mangweth et al., 2011).

1.3 Project background

In a previous study at the Bavarian State Research Centre for Agriculture, Germany, various performance and behavioural parameters were analysed in order to develop a predictive algorithm with aim of recognising lame animals (Schindhelm, 2016; Schindhelm et al., 2015).

The aim of the follow-up study is to expand on the results of Schindhelm (2016) and test the algorithm on a larger number of animals using lying and feeding behaviour traits in consideration of individual animals parameters (such as the lactation number and the days in milk). These are the parameters which proved to have the highest correlation with episodes of lameness.

The "TAC" pedometers will be used to monitor the lying and feeding behaviour of the animals in the current study so the aim of this study was to test the precision and accuracy of two automatic activity measuring systems and to evaluate their cost-benefit ratio.

2. Animals, materials and methods

2.1 Animals and housing

The study took place in February 2017 in a free standing cubicle barn in Grub, Germany. The herd consists of 65 lactating Simmental cows milked with a robotic milking system.

For the study, 28 animals were randomly selected from the herd and marked with numbers on their haunches for visual recognition. Eight of the animals were in their first lactation at the time, nine animals in their second, five in their third, four in their fourth, and two in their fifth lactation.

The first ten animals were observed for 20 hours over a period of three days, then a further eight animals were observed for five hours on a subsequent day, and again another ten animals for five hours on the fifth day, totalling 30 hours of observation (n=200 datasets for the "ALT" pedometers and n=290 datasets for the "TAC" pedometers).

During the hoof-trimming session in December 2016 all animals in the herd were fitted with a "TAC" Pedometer on the right forelimb above the fetlock.

The ten animals observed on the first three days were also fitted with an "ALT" pedometer on their left forelimb above the fetlock joint.

2.2 The pedometers

The "TAC" pedometers are three dimensional accelerometers enclosed in a 6,88 cm x 5,07 cm x 2,65 cm rigid plastic housing which is fitted to the animal's forelimb with a webbing strap. The pedometers measure acceleration at a frequency of 1000 Hz and transmit data regarding the lying, activity and feeding behaviour of each animal every 15 minutes to a receiver, which is connected to an on-farm computer via a RS485 cable. The information is then collected in a database that generates various queries based on the information received; the queries used in this study were those that describe the animals' lying behaviour. The data sets collected in the database are then displayed for the end user in the "Eco Herd" Software (ENGS Systems, Rosh Pina, Israel). The software offers on-heat detection as well as information regarding the health status of the animal, based on the individual parameters. Moreover, the installation of an induction loop along the feeding table and at the feeding stations enables individual monitoring of the animals' feed intake, which is important especially in the early stages of lactation after calving.

The "ALT" Pedometers are activity loggers enclosed in a 6 x 5 x 2 cm case attached by means of a webbing strap on the animals' leg above the fetlock joint. Each pedometer contains four sensors; one for outside temperature measurement, two lying sensors; respectively one for the normal lying position (thorax and abdomen resting on the ground, legs folded underneath) and the side lying position (legs stretched out to the back or to the side), and one for activity. Activity is measured using an analogue piezo-sensor and the lying time with digital position sensors. A µ processor contained inside the "ALT" Pedometer records the activity and lying behaviour of each animal continuously every 15 seconds and adds up the collected data over a time interval which can be decided by the user and set to any value between 1 and 99 minutes (Alsaaod and Büscher, 2009). At the end of the selected measuring interval the data is stored in the internal memory unit.

The memory is then read out cyclically and transmitted to a PC via a central antenna mounted in the barn (Brehme et al., 2006).

2.3 Data collection

The lying episodes of the animals involved in the study were recorded by an observer standing in an elevated position in the barn. The observer recorded the lying time and the time each animal took in the process of lying down and standing up using a purposely programmed HTML page which converted the input data into a text file.

An ethogram was decided for each activity: lying was defined as the animal lying on the ground with all four limbs bent underneath it, and the process of lying down was defined as the animal changing from a standing position to a lying one, starting at the moment when it bends its forelimbs at the carpal joint and ending when it is lying down with all four limbs bent at the carpal and tarsal joints. The process of standing up was defined as the period of time between the animal extending its back limbs at the tarsal joint and lifting its hindquarters, and the moment the animal is standing with all four limbs fully extended.

3. Results

3.1 Data conversion and processing

The data recorded by the observer was converted from a text file and processed using an SQL database and Microsoft Excel. The data was then summarized into one hour intervals, so that the output data set consisted of the animal's ID, the activity trait, and the number of minutes for said activity trait per hour. The number of minutes per hour lying activity from the direct observation was then compared with the data from the "TAC" and "ALT" pedometers.

Data sets were excluded from the statistical analysis if the animal was not visible for a full hour. A total 268 datasets were compared for the "TAC" pedometers and 190 for the "ALT" pedometers.

3.2 Data analysis

The data was then analysed using the statistical software "R Studio". Firstly, the data was tested for distribution using the Shapiro-Wilk test (W=0.81753, p < 0,001 for the direct observation, W=0.84394, p<0,001 for the "TAC" pedometers, and W=0.80533, p < 0,001 for the "ALT" pedometers) and a visual normality check was performed using a frequency distribution plot (Figure 1).

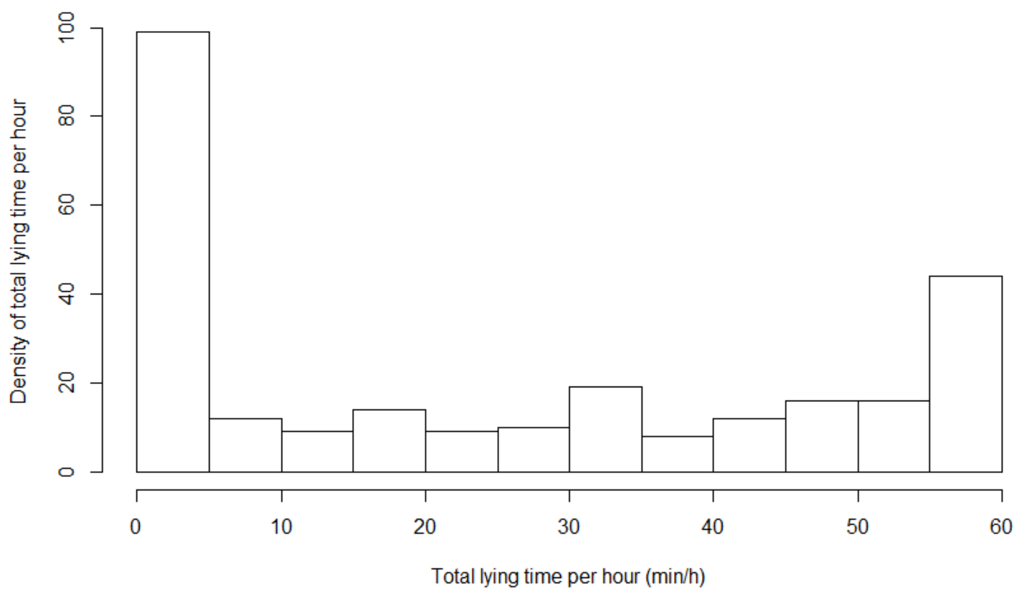

Figure 1: Density of lying duration per hour (n=268) measured by direct observation.

The mean values (M) and standard deviation (s) of the lying duration per hour for all three methods were calculated: M=23,53 ± s=23,58 min/h (direct observation), M=24,9 ± s=23,15 min/h ("TAC"), and M=23,3 ± s=23,86 min/h ("ALT").

The mean and standard deviation of the difference between lying time measured by direct observation minus the lying time measured by the "TAC" pedometers was M(diff)=1,37 ± s=6,32 min and M(diff)=-0,83 ± s=5,72 min for the "ALT" pedometers.

Scatter plots were created to visually demonstrate the level of agreement between the data collected by the pedometers and the direct observation (Figure 2 and Figure 3).

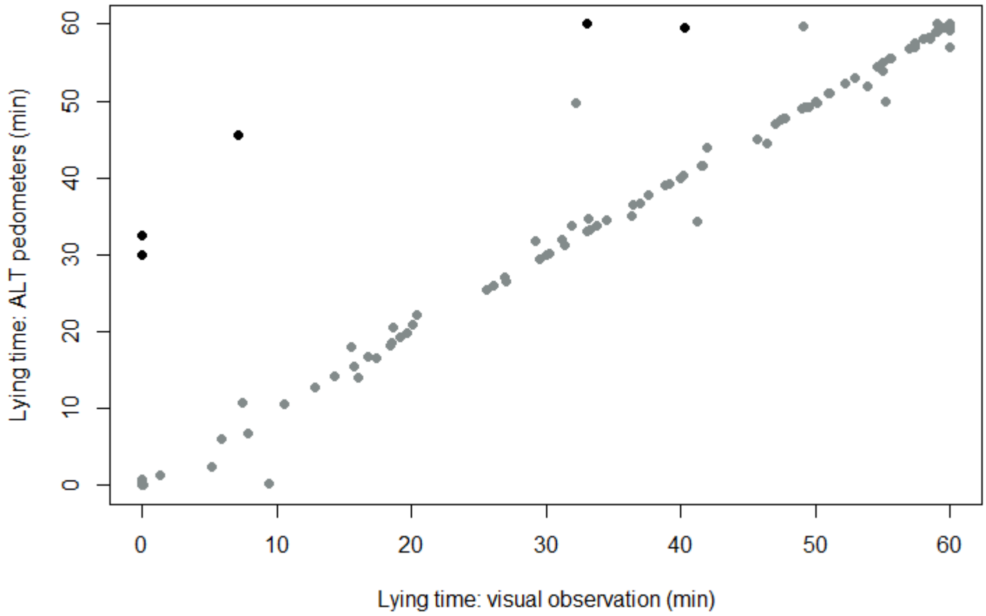

Figure 2: Scatter plot of min/ h lying time by direct observation vs. "ALT" pedometers. The outliers are marked in black.

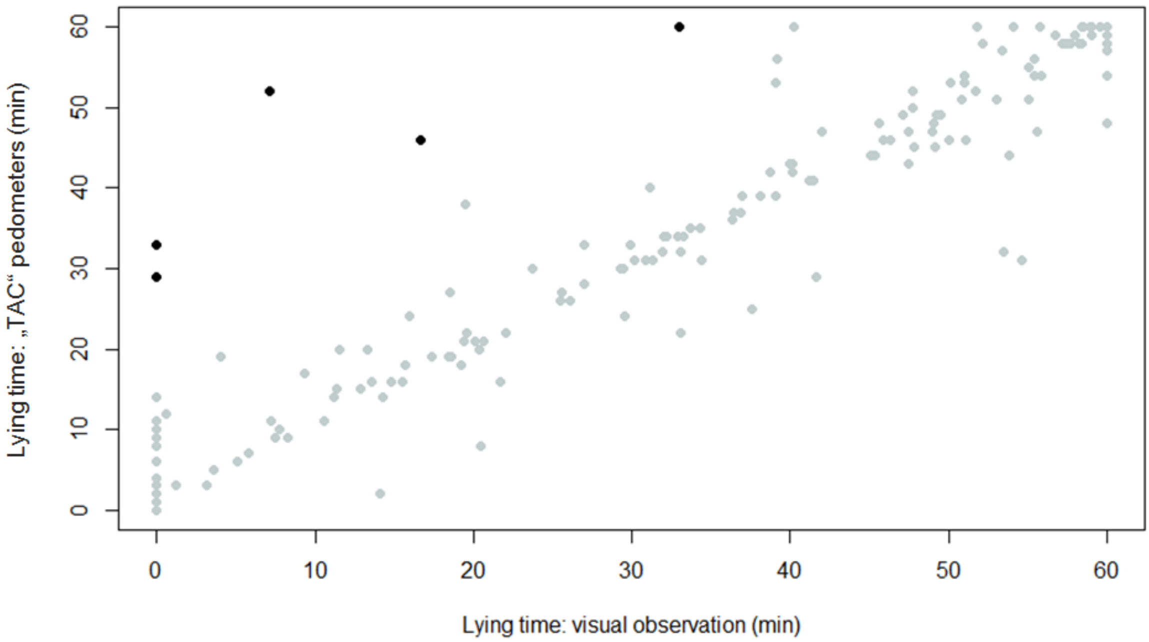

Figure 3: Scatter plot of min/ h lying time by direct observation vs. " TAC " pedometers. The outliers are marked in black.

4. Discussion

4.1 Means and Data distribution

The results from the Shapiro-Wilks test and also the frequency distribution plot show that the data is not normally distributed in any of the three cases as $p>0,05$ and $W<1$ (Das and Imon, 2016; Ghasemi and Zahediasl, 2012), but this is not surprising as cows' lying bouts are often 60 min or longer (the length of cows' lying bouts is on average 95,2 ± 30,8 min (DeVries et al., 2010)). The high number of short lying bouts on the other hand could be explained by the fact that all direct observations were conducted during the daytime (8 am until 5 pm) when animals are more restless and lie for shorter periods of time than at night time. Moreover, because the data from the direct observation was divided into one hour intervals to make it comparable with the pedometer data, all observed lying bouts which extended over the full hour were cut off at the full hour and the remaining time was counted in the next hour as a new data set. For this reason the number of lying episodes per hour doesn't correspond to reality.

The mean difference was marginally higher for the "TAC" pedometers, meaning they measured on average slightly less lying time than the direct observation, whereas the opposite can be said for the "ALT" pedometers; they measured on average longer lying times.

4.2 Outliers

In the final method comparison 5 data sets were outside the 95 % confidence interval for both the "TAC" and the "ALT" pedometers. To define the aforementioned outliers the data (graphically represented in the histogram in Figure 1) was logarithmically transformed and the confidence interval was then calculated.

Most of the outliers were below the minimum value for the confidence interval, showing that in these cases the pedometers measured longer lying times than those recorded per direct observation.

The presence of outliers could be due to measurement errors from the pedometers and/or errors in the direct observation. The outliers are visually highlighted in black in Figure 2 and in Figure 3.

4.3 Concordance correlation coefficient

The consistency of a measuring process can be defined as whether two techniques used to measure a particular variable, under identical circumstances, produces essentially the same result (Watson and Petrie, 2010).

As direct observation is considered to be the gold standard in this study, it is of interest to find out whether the automated measuring methods are consistent with the method of reference.

To determine the precision and accuracy of the pedometers in relation to direct observation the concordance correlation coefficient (ρ_c) was calculated; the results show a strong level of agreement for both pedometers with the direct observation ($\rho_c = 0,96$ for the "TAC" pedometers in comparison to the direct observation and $\rho_c = 0,98$ for the "ALT" pedometers).

The concordance correlation coefficient (ρ_c) contains a measurement of precision ρ and accuracy Cb, where ρ is the Pearson correlation coefficient, which evaluates the agreement between two readings by measuring the variation from the 45° line through the origin (the concordance line), and is a measure of precision, and Cb is a bias correction factor that measures how far the best-fit line deviates from the 45° line through the origin, and is a measure of accuracy (Lin, 1989).

5. Conclusions

5.1 The relevance of this study

The aim of this study was to evaluate the precision and accuracy of two types of pedometer that could be used for lameness detection in dairy cattle.

To the author's knowledge, to this day no previous study has been conducted validating the "ALT" pedometers. Although Alsaaod et al (Alsaaod et al., 2012) conducted a study in which the efficiency of electronic measurement of activity and lying behaviour was evaluated using the "ALT" pedometers, no comparison was made with visual observation.

Brehme et al (Brehme et al., 2006) tested objective measuring systems for heat detection in dairy farms comparing them to visual heat detection performed by staff, but did not evaluate the precision of the lying measurements.

5.2 Use of the "TAC" and "ALT" pedometers for research purposes

Although the concordance correlation coefficient was higher for the "ALT" pedometers ($\rho_c = 0,98$) than for the "TAC" pedometers ($\rho_c = 0,96$), some factors make the "TAC" pedometers more suitable for on-field research. The battery life is longer (1,5 years for the ALT pedometers compared to 4 to 5 years for the "TAC" pedometers according to the manufacturers), and although the battery in the "TAC" pedometers cannot be changed, the acquisition cost for new pedometers is still less than the cost of sending the "ALT" pedometers to the producers to have the battery changed. The reception range for the “TAC” pedometers is much better (up to 2000 m range according to the manufacturers, versus 25 m range for the “ALT” pedometers) and also the use of the database queries in MS Access facilitates data processing and makes the “TAC” more user-friendly compared to the “ALT” pedometers’ database. Nonetheless, the “ALT” pedometers have a higher data resolution (up to one minute compared with the “TAC”’s one hour data sets in the MS Access database), allowing the user to identify lying bouts more precisely and assign them to a precise time of day.

In conclusion, findings in the current study demonstrate that although both types of pedometer are valid instruments for measuring cows’ lying time, the “TAC” pedometers are suitable for on-field research and day-to-day use alike, whereas the “ALT” pedometers are restricted to use over short periods of time and solely for research purposes.

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