Validation of RumiWatch pedometers measuring lying, standing and walking of cattle

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Abstract

Information on resting behaviour and locomotion can be used as indicators of production, health and welfare status of dairy cows. RumiWatch pedometer (ITIN+HOCH GmbH, Switzerland; RW) is an accelerometer based system that automatically measures cows’ lying (LT), standing (ST) and walking times (WT). The aim of this study was to validate these measurements against video-based continuous behaviour recording (VCR).

Six dairy cows were housed in pens (3x6m) and equipped with RW pedometers fastened to the right hind leg of the cows. RW data was registered to SD memory cards of the pedometers at 10 Hz frequency. LT, ST and WT (min/h) of the cows were monitored from videos continuously for 12-15 hours/cow. The behaviour was registered as LT when the cow was lying on the sternum head up or flat on the side head stretched on the ground, and ST when the cow stood on all four legs. WT was registered when the cow moved all legs bringing itself to another location within the pen. Other hind leg movements (not leading to a spatial dislocation of the animal) were added to WT to form an “all leg movement” (ALM) behaviour category.

The data was processed as min/h for each behaviour class. Individual hours (in total 81 h) were used as separate observations in the statistical analyses. The agreement between RW and VCR was assessed for the LT, ST, WT and ALM by Mixed procedure of SAS using the random coefficient regression model clustered by a cow. In the model, RW variables were on the Y and VCR variables on the X axis. The hypothesis was that for each behaviour pattern the intercept was 0 and the slope 1. The deviation of the intercept from 0 (min/h) and 95% confidence interval for the slope were analyzed as indicators of systematic error. Coefficients of determination ($R^2$) were calculated between adjusted Y and X as the indicators of random error. The magnitudes of the error between RW and VCR are illustrated with the medians and maximums of the absolute errors (min/h) for each behavioural variable calculated from all observation hours.

The agreement between RW and VCR results was very good for LT (intercept = 0.026, $P = 0.895$, slope = 1.001 ± 0.008, $R^2 = 0.999$, median error = 0.2, maximum error = 5.3) and ST (intercept = 0.035, $P = 0.926$, slope = 0.979 ± 0.084, $R^2 = 0.989$, median error = 0.9, maximum error = 14.1). For WT the agreement between RW and VCR was worse (intercept = 1.062, $P = 0.043$, slope = 1.970 ± 0.933, $R^2 = 0.687$, median error = 1.5, maximum error = 19.0), but improved when all leg movements were taken into account (ALM: intercept = -0.013, $P = 0.962$, slope = 1.091 ± 0.414, $R^2 = 0.888$, median error = 0.9, maximum error = 14.2).
To conclude, RW measures for cows’ LT and ST were free from both systematic and random error. There is still a need to improve the accuracy and precision of RW for WT.

Keywords: cow, health, locomotion, automation, measure

1 Introduction

Information on resting behaviour (e.g. Vasseur et al. 2012; Mattachini et al. 2013) and locomotion (e.g. Nielsen et al. 2010) of dairy cows can be used as an indicator of the welfare status of the animals. However, collecting individual behavioural data is very labour intensive (e.g. Elischer et al. 2013), especially in large herds. Therefore there is plenty of research devoted to automated monitoring of health issues and reproductive status in cattle (c.f. review by Rutten et al. 2013).

Standing, lying and walking of individual cows can be monitored with devices attached to a leg. These pedometers measure locomotion by three-dimensional acceleration technology (e.g. Nielsen et al. 2010) or by a tilt switch (e.g. Mattachini et al. 2013) that respond to the position changes of the leg. Devices measuring locomotion have been used for example for estrus (e.g. Roelofs et al. 2005) and lameness (e.g. Mazrier et al. 2006; Chapinal et al. 2011) detection. Automated devices measuring lying behavior, i.e. resting time of cows (e.g. Ito et al. 2009; Ledgerwood et al. 2010; Vasseur et al. 2012; Mattachini et al. 2013) could be used to assess cow comfort in different management systems.

RumiWatch pedometer (ITIN+HOCH GmbH, Switzerland; RW) is an accelerometer based system that automatically measures cows’ activity related behaviour. The RumiWatch system also includes a halter that measures cows’ feeding behaviour with pressure sensor technique. The advantage of RumiWatch system is that it combines feeding and locomotion measurements. Integrated systems with the ability to collect diverse data are essential if management of large herds is made more and more automatic. To our knowledge, there are no other devices available that measure both feeding and locomotion of cows.

Validation of RumiWatch feeding behaviour measurement is currently in progress (Zehner et al. 2012; Kajava et al. unpublished data). The objective of the present study was to validate lying, standing and walking time measurements of RW against video-based continuous behaviour recording.

2 Materials and methods

2.1 Animals and housing

All management and experiment procedures were performed according to the Finnish animal welfare legislation. In the experiment, six non-lactating multiparous dairy cows were housed in pens (3x6m) at research barn of MTT Agrifood Research Finland. The cows were fed grass silage (DM 25 - 35%) delivered two times a day during the two-day experiments. Water was provided ad libitum from water bowls.

2.2 Measurements

RW is a system recording automatically cows’ lying, standing and walking times (Zehner et al., 2012). Additionally, RW records the frequencies of lying and standing up bouts and step amounts of cows, but these were not validated in the present study. The measurements of the system are based on a three-dimensional accelerometer attached in the pedometer which is fastened on a cow’s leg. Pedometers register data at 10 Hz frequency. The raw data can be saved to a SD memory card situated in the pedometer or, alternatively, read at hourly
intervals if the data is transferred to a computer wirelessly. Behaviour data are represented in a computer application (RW manager) as one-hour summaries.

In the experiment, RW pedometers were fastened to the right hind leg of the cows above the metatarsophalangeal joint (Figure 1) as instructed by the manufacturer. Cows were habituated to pedometers a few hours before the behavioural observation started. The used firmware version was V01.13 and data converter version 0.7.0.0. RW data was registered to SD memory cards of the pedometers at 10 Hz frequency. Two video cameras (Axis Q1755-E, Axis communications AB, Sweden) recorded with Media Recorder 2.5 (Noldus Information Technology, The Netherlands) the behaviour of the cows continuously 24 hours for each animal. The clocks of the Media Recorder and RumiWatch pedometers were synchronized before the experiment.

![Image](image1.jpg)

**Figure 1. RumiWatch pedometer fastened on a cow's leg.**

Two trained observers monitored from videos the lying (LT), standing (ST) and walking times (WT) (Table 1) of six cows by continuous recording (VCR) (Martin and Bateson, 2007) with Observer XT 11.5 software (Noldus Information Technology, The Netherlands). Cows may move their legs without walking or walk so slowly that no leg activity is recorded (Nielsen et al. 2010), and thus other hind leg movements (not leading to a spatial dislocation of the animal) were added to WT to form an “all leg movement” (ALM) behaviour category. A total of 12 hours for three cows and 15 hours for another three cows were observed. The inter-observer reliability (Martin and Bateson, 2007) was tested with Observe XT 11.5 software by comparing one hour observation period of both observers. Agreement for the durations of all four behaviour classes was more than 90%.
Table 1. Behaviour categories used in the continuous behaviour recording. Lying, standing, walking and all leg movements (min/h) of the cows were monitored from videos 12-15 hours/cow.

<table>
<thead>
<tr>
<th>Behaviour class</th>
<th>Description</th>
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<tbody>
<tr>
<td>Lying (LT)</td>
<td>The cow is lying on the sternum head up, or flat on the side head stretched on the ground.</td>
</tr>
<tr>
<td>Standing (ST)</td>
<td>The cows’ body is supported by all four legs.</td>
</tr>
<tr>
<td>Walking (WT)</td>
<td>The cow moves all legs bringing itself to another location within the pen, walking ends when all the legs are still again.</td>
</tr>
<tr>
<td>All leg movements (ALM)</td>
<td>Other hind leg movements (not leading to a spatial dislocation of the animal) added to WT.</td>
</tr>
</tbody>
</table>

2.3 Statistics

The RW and VCR data were processed as min/h for each behaviour category. The statistical analyses were done by using SAS software (software for Windows version 9.3, SAS Institute Inc., Cary, NC, USA). The random coefficient regression model was used to reveal random errors (St-Pierre, 2001) between RW and VCR measurements. The agreement between RW (on y axis) and VCR (on x axis) was assessed for the LT, ST, WT and ALM (min/h) by The Mixed procedure of SAS. The used model was

\[ Y_{ij} = B_0 + B_1 X_{ij} + s_i + b_i X_{ij} + e_{ij}, \]

where \( B_0 \) is the overall intercept (fixed effect), \( B_1 \) is the overall regressing coefficient of \( Y \) on \( X \) (fixed effect), \( s_i \) is the random effect of cow \( i (i = 1, \ldots, n) \), \( b_i \) is the random effect of cow \( i \) on the regression coefficient of \( Y \) on \( X \) in cow \( i \) and \( e_{ij} \) is the unexplained residual error. \( J \) is the number of observations on each cow.

Adjusted \( Y \) values were calculated by adding \( Y \) value on the overall regression line and residual between an individual observation \( ij \) and \( Y \) value on the regression line of cow \( i \). Coefficients of determination \((R^2)\) were calculated between adjusted \( Y \) and \( X \) as an indicator of the random error. Coefficient of determination \((R^2)\) was performed fitting the regression line between adjusted \( Y \) values and \( X \) values using the Reg procedure of SAS.

An unstructured covariance matrix was used for calculating the intercepts and slopes. The hypothesis was that for each behaviour pattern the slope of the regression line was 1 and the intercept was 0, i.e. perfect agreement between the two methods \((y = x, \text{c.f. Mattachini et al., 2013})\). The regression model calculated the deviation of the intercept from 0 (min/h), whereas the deviation of the slope from 1 was interpreted from the 95% confidence intervals. These two deviations were used as indicators of systematic error, i.e. whether the error remains constant or varies in a predictable manner (c.f. JCGM, 2008).

The magnitudes of the error between RW measurements and VCR recordings were illustrated with the medians and maximums of the absolute errors (min/h) for each behavioural variable calculated from all observation hours.

3 Results and Discussion

Lying and standing times measured by VCR and RW had a very dependable relationship (Table 2), and median errors between the measures (min/h) were low: 0.2 for lying and 0.9 for standing time. However, there occurred some random errors in the measures which can be seen in the maximum errors of the measures (min/h): 5.3 for LT and 14.1 for ST. Never-
theless, the high coefficients of determination confirmed that the random errors across the measures of RW LT and ST were not frequent.

Slopes of the comparison of RW and VCR results for lying and standing times were close to 1, and also the 95% confidence interval included the value 1 (Table 2). The values of the intercepts of lying or standing times did not differ statistically from 0. These results indicate that there were no systematic errors in the measures of RW lying or standing times.

Earlier studies have also reported good correlations between visual observations and devices measuring automatically cows’ lying and standing times (e.g. Robert et al. 2009, Ledgerwood et al. 2010, Mattachini et al. 2011). The advantage of RW compared to the other automated devices is that it can measure several important behaviour of a cow at the same time. Automatic lying and standing time measurements can be utilized e.g. when studying the rearing environments of dairy cows (i.a. comfort of stalls).

In contrast with the lying and standing time measurements of RW, there occurred both random and systematic errors in the walking time measures (Table 2). Also in earlier studies walking time has been inadequately recorded (probability of correct positive classification < 0.303 in Mattachini et al. 2011; walking classification accuracy 67.8 % in Robert et al. 2009). In our study the median error between RW and VCR (min/h) was 1.5 and maximum error (min/h) 19.0. When other hind leg movements (i.e. all movements which did not lead to spatial dislocation of the animal) were added to the walking time of the cows the agreement between RW and VCR improved markedly (Table 2). The median error decreased to 0.9 min/h, but the maximum error between the measurement techniques remained quite high (14.0 min/h). In addition, the systematic error in the RW measurements decreased: slopes of the comparison of the RW and VCR measures were close to 1, the 95% confidence interval included 1, and the values of the intercepts of measures did not differ statistically from 0.

In our study RW were tested only on right hind leg. However, Müller and Schrader (2003) found that measuring activity from different hind legs produced slightly different results. Thus, in the future a research effect of pedometer position on lying, standing and walking time measurements should be studied.

### Table 2. Relationship between RW and VCR measurements of lying, standing and walking times and time when all hind leg movements were taken into account by six dairy cows with 12-15 hours of observations per cow. The coefficients of determination ($R^2$), slope and its 95% confidence interval (95% CI) and intercept and its standard error of the mean (SEM) in the experiment are based on a regression model with 81 one-hour periods (see text for the details of the statistical model).

<table>
<thead>
<tr>
<th></th>
<th>Lying</th>
<th>Standing</th>
<th>Walking</th>
<th>All leg movements</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R^2$</td>
<td>0.999</td>
<td>0.989</td>
<td>0.687</td>
<td>0.888</td>
</tr>
<tr>
<td><strong>Slope (95% CI)</strong></td>
<td>1.001 (0.992 - 1.008)</td>
<td>0.979 (0.916 - 1.084)</td>
<td>1.970 (0.067 - 1.933)</td>
<td>1.091 (0.586 - 1.414)</td>
</tr>
<tr>
<td><strong>Intercept (min/h, SEM)</strong></td>
<td>0.026 (0.186)</td>
<td>0.035 (0.355)</td>
<td>1.062 (0.394)</td>
<td>-0.013 (0.253)</td>
</tr>
<tr>
<td>$P$-value$^1$</td>
<td>0.895</td>
<td>0.926</td>
<td>0.043</td>
<td>0.962</td>
</tr>
</tbody>
</table>

$^1$Probability that the intercept differs from zero.
4 Conclusions

In conclusion, RW is a reliable device for measuring lying and standing times of dairy cows. On the contrary, measurements of RW walking time are less satisfactory.

5 References


