Methodology for quantifying the behavioral activity of dairy cows in freestall barns

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ABSTRACT: The objectives of this study were to
1) evaluate the validity of automated monitoring sys-
tems as assessment method for the behavioral activity
of dairy cows compared with video recording, and 2)
determine the sampling intervals required to obtain
reliable estimates of the daily behavior. To determine
lying, standing, and walking, 12 cows were equipped
with automatic recording devices (IceTag = 12 cows,
HOBO Pendant G = 5 cows), and their behavior was
simultaneously recorded using a video recording sys-
tem. The correspondence between the IceTag, HOBO
logger, and video recording data was analyzed using
2 × 2 contingency tables, and we determined the sen-
sitivity, specificity, and predictive value (positive and
negative). Both types of loggers demonstrated high
sensitivity (Sen ≥ 0.961) and specificity (Sp ≥ 0.951)
for lying and standing behaviors with predictive values
near 1.00. The HOBO logger can accurately describe
the laterality of lying behavior, whereas the IceTag
device inadequately recorded walking, with probabil-
ity predictive values ≤ 0.303. Daily behaviors of the
dairy cows were compared for 10 different sampling
intervals (1 s, and 1, 2, 3, 4, 5, 10, 15, 30, and 60 min)
collected by the IceTag, using linear regression. A
strong relationship ($R^2 ≥ 0.978$) was found between
the total lying times from data on a per-second basis
and estimates obtained by 1, 2, 3, 4, 5, 10, and 15 min
sampling intervals. The sampling intervals of 1 and
2 min were comparable for all aspects of lying behav-
ior ($R^2 ≥ 0.813; P > 0.05$ for slope = 1, intercept =
0). Long sampling intervals (30 and 60 min) showed
positive relationship for estimating time spent lying
and standing ($R^2 ≥ 0.774$), but were inappropriate for
predicting these behaviors, because they lacked accu-
racy and precision. Both the IceTag and HOBO logger
accurately measured all aspects of lying and standing
behavior. Reliable estimates of lying and standing
time can be generated using relatively short interval lengths
(e.g., 3, 4, 5, 10, or 15 min). Shorter sampling intervals
(≤ 2 min) are required to accurately measure aspects
of lying behavior such as number of lying bouts per
day. The automated monitoring systems are time- and
labor-saving tools that can be used by research or on
farm to assess cow comfort related to lying behavior.

Key words: accelerometer technology, automation
of monitoring, daily behavior, dairy cow, data loggers, video recording

INTRODUCTION

Behavior is one of the most commonly used and
sensitive indicators of animal welfare (Krohn and
Munksgaard, 1993; Haley et al., 2001). The time spent
lying down, the number and duration of lying bouts
(Haley et al., 2000), and the laterality of lying behavior
(Tucker et al., 2009) can indicate underlying changes in
cow comfort and welfare. On-farm monitoring of cow
behavior requires investments in labor, equipment, time
and money, particularly when the number of animals
per pen is high. Methods of assessing behavioral ac-
tivity have changed in recent years towards techniques
that automate sampling. Recent developments in sen-
sor technology (e.g., accelerometers) have created new
opportunities for the automated monitoring and record-
ing of animal behavior beyond what can be achieved using a video recording system (VRS) or direct observation (Müller and Schrader, 2003; McGowan et al., 2007; O’Driscoll et al., 2008; Ledgerwood et al., 2010).

Various authors chose and validated the sampling intervals based on the data logger features, the behavioral patterns assessed, or the type, objectives, and structure of the experiment. In the literature, sampling intervals evaluated to record animal behavior have ranged from multiple readings per second to several minutes. Ledgerwood et al. (2010) accurately measured lying behavior with data loggers when the sampling interval was ≤ 30 s. Mitlöhner et al. (2001) showed that scan samples of 30 or 60 min are suitable for measuring lying time. However, the influence of the different monitoring systems on the reliability of the recorded (behavioral activity) for different sampling intervals has not been fully investigated for all types of loggers.

The objectives of the current study were to 1) evaluate the validity of automated monitoring systems [HOBO Pendant G (Onset Computer Corporation, Pocasset, MA) and IceTag (IceRobotics, Edinburgh, UK)], compared with video recording, as methods to measure lying, standing, and walking of dairy cows and 2) assess the sampling intervals required to obtain reliable estimates of the daily behavior of dairy cows.

MATERIALS AND METHODS

We collected the data for this study at a commercial farm in such a way that our monitoring actions and procedures did not affect the behavior of the cows and did not change the comfort or welfare of the animals monitored.

Housing, Animals, and Feeding

The study was conducted at a commercial dairy farm (Mts Zeinstra, Stiens, the Netherlands, 53°15’ 50.00” N, 5°48’ 53.00” E). The barn was east-west oriented and featured a loose-housing layout with a total of 141 cubicles, 61 feeding places, 2 voluntary milking system (VMS) units (DeLaval International AB, Tumba, Sweden), and an automatic feeding system for mixed rations (Mix Feeder mod. XL; Skiodl Mullerup A/S, Ullerslev, Denmark). At the time of the study, the barn housed 107 lactating Holstein-Friesian cows [parity 2.4 ± 1.3, milk yield 33.0 ± 6.6 kg/d, DIM 191.0 ± 107; mean ± SD] of these lactating cows [parity 2.7 ± 1.4, milk yield 33.6 ± 5.5 kg/d, DIM 191.0 ± 107; mean ± SD] were randomly selected (excluding unhealthy cows) and equipped with 2D IceTag automatic recording devices (IceTag 2.004, IceRobotics). Five (parity 3.2 ± 1.2, milk yield 35.6 ± 5.5 kg/d, DIM 160 ± 128; mean ± SD) of these 12 cows were also equipped with a HOBO Pendant G Acceleration Data Logger (Onset Computer Corporation).

The 12 cows that were equipped with recording devices were marked with unique numbers dyed onto both sides of their bodies and on their buttocks to facilitate quick identification during the video recording analysis. Number of milkings, milking times, and duration of individual visits to the milking robot for each cow were obtained through the VMS software.

IceTag. The IceTag unit is an electronic sensor device based on accelerometer technology that records and reports animal activity. The IceTag devices measure and determine for each recording (1 s) the percentage of time the cows spent lying (L_p), standing (S_p), or active (A_p), and the number of steps based on sample frequency of 8 Hz.

The device has a length × width × height of 95 × 85 × 32 mm, weighs 210 g, and can store up to 30 d of activity between downloads. The device has a rigid plastic housing designed to withstand the farm environment and attaches to the lateral side of the right hind leg above the fetlock by a strap with a buckle.

Activity data were downloaded with a dedicated Universal Serial Bus (USB) cable and the IceTagAnalyser software (versions 2.009; IceRobotics) from the on-board memory of the IceTag unit to a personal computer (PC) on a per-second and per-minute basis and were exported to an Excel 2007 spreadsheet (Microsoft Corp., Redmond, WA). We followed the approach that Trénél et al. (2009) developed for calves and classified cow behavior for each recording (1 s) after the IceTag-recorded percentage thresholds for lying (L_p ≥ 50% of recorded time), standing (S_p ≥ 37.5% of recorded time), and walk-
ing ($A_p \geq 50\%$ of recorded time). Finally, per-second and per-minute data were edited with filters to remove the effect of short, potentially erroneous readings of lying or standing events. These filters (event criterion) converted readings to the behavior preceding them (e.g., lying events bordered by standing) if they occurred $\leq 25$ per second and $\leq 2$ per minute in consecutive runs.

**HOBO Pendant G.** The HOBO logger is a waterproof 3-channel logger with 8-bit resolution, which can record up to approximately 21,800 combined acceleration readings or internal logger events. The logger uses an internal 3-axis accelerometer with a range of $\pm 3$ g (accuracy $\pm 0.075$ g at $25^\circ$C with a resolution of 0.025 g) based on micromachined silicon sensors consisting of beams that deflect with acceleration. The data loggers (dimensions: height 58 mm $\times$ width 33 mm $\times$ depth 23 mm; weight: 18 g) were attached to the lateral side of the left hind leg of the cows using Vet-flex (Kruuse group, Langeskov, Denmark) in a position such that the x-axis was perpendicular to the ground and pointing towards the back of the cow (dorsal direction), the y-axis was parallel to the ground pointing in the cranial direction, and the z-axis was parallel to the ground pointing toward the midplane. The loggers were programmed to record the g-force on the x, y, and z-axes at 1 min intervals using the procedure of Ito et al. (2009).

The HOBO logger uses a coupler and an optical base station with a USB interface to transfer data to a computer. The logger data were downloaded with Onset HOBOware software version 3.1.2 (Onset Computer Corporation, Pocasset, MA), which converted the g-force readings into degrees of tilt. These data were exported into an Excel 2007 (Microsoft) spreadsheet. The degree of vertical tilt (x-axis) was used to determine the posture of the animal, such that readings $< 60^\circ$ indicated standing behavior, whereas readings $\geq 60^\circ$ indicated lying down behavior (Ito et al., 2009). We used the degree of z-axis tilt to determine the laterality of lying behavior, such that readings $\leq 100^\circ$ indicated the cow was lying on the right side, whereas readings $> 100^\circ$ indicated the cow was lying on the left side. This cutoff value was based on preliminary observations from the video recordings. Finally, data were edited with a filter in a similar approach as for the IceTag devices: readings that lasted $\leq 2$ min in consecutive runs were converted to the behavior preceding them. We did not analyze walking for this device because the 1 min sampling interval is considered too long for this purpose.

**Video Recording.** The behavior of the animals was continuously recorded by VRS for the complete duration of the study. The video surveillance system consisted of 4 infrared day/night weatherproof varifocal cameras (SONY Color CCD, Tokyo, Japan) with 42 infrared light-emitting diodes (LED) for night vision (420SS-EC5; Vigital Technology Ltd., Sheung Wan, Hong Kong) and a recording PC running Windows XP Professional (Microsoft Corp., Redmond, WA). The cameras had a protective aluminum housing (IP66) and a 4.0 to 9.0 mm varifocal lens. The 4 cameras were attached to beams in the barn approximately 5 m above the pen floor so that they covered the complete living area of the barn, including the entrance and exit of the VMS. The cameras were connected to a 4-channel video capture 4 EYES Pro card (AVerMedia Technologies, Inc., Milpitas, CA) that was integrated into the PC and that converted the analogue signal to a digital signal for subsequent storage on a hard disk. Each camera was set to continuously record at 320 $\times$ 240 resolution and 6 frames/s.

One trained observer classified the behavioral activities (standing, lying, and walking) of the cows as follows: standing was defined as an upright body with support from at least 3 legs, lying as body contact with the ground on the left or right side, and walking as moving of at least 3 legs forward in sequence. Standing behavior was further subdivided into feeding as head over in the bunk, drinking as head over or in the water trough, idle standing (standing in a stall with all 4 feet), perching (standing in a stall with the rear 2 feet in the alley), and standing in the alley for all the other cases (Cook et al., 2005). The video analysis was performed by 1 trained observer with a within-observer reliability of 97.3% agreement for the behavioral activities analyzed. Reliability was expressed as a Pearson correlation coefficient ($\text{PROC CORR;}$ SAS Inst. Inc., Cary, NC; $r = 0.99$, $P < 0.001$) for a subset of the data set (5 cows for 6 h).

**Data Analyses**

**Comparison of the Behavioral Activity Data Obtained by the Electronic Recording Devices and by the VRS.** To quantify the ability of the automatic recording devices to monitor behavioral activities and their accuracy compared with the VRS, we analyzed 24 h of behavioral data on d 2 for the 5 cows that were equipped with both the IceTag and HOBO units. To determine the accuracy of the devices, we analyzed the behavioral activities of the 5 cows by video recording with the aid of the continuous sampling method (Martin and Bateson, 2007). A trained observer watched the video continuously and recorded the times (start and stop of the individual behavioral events) of different behaviors with 1 s accuracy to compute frequencies and durations of each behavior. We then created 4 comparisons as follows: IceTag vs. video recorded data at the level of 1 s, IceTag vs. video recorded data at the level of 1 min, HOBO vs. video recorded data at the level of 1 min, and IceTag vs. HOBO processed data at the level of 1 min. The correspondence between IceTag, HOBO logger, and video recording data were
RESULTS

Comparison of the Behavioral Activity Data Obtained by the Electronic Recording Devices and by the VRS

Examples of the behavior 1 cow, obtained from the video and raw data recorded by the data loggers are reported in Fig. 1. Lying behaviors and laterality patterns in this figure are marked with the dashed boxes. The HOBO logger determined 5 lying bouts (x-axis tilt ≥ 60°). For 2 of these bouts, the lying laterality was right (z-axis tilt ≤ 100°), whereas for the other 3 bouts the lying laterality was left (z-axis tilt > 100°). The IceTag also determined 5 lying bouts (percentage lying of recorded time ≥ 50%).

Video observation detected lying and standing as the dominant behavioral patterns in all 5 dairy cows monitored with a lying prevalence of 38 ± 3% (mean ± SE) and a standing prevalence of 37 ± 5% (Table 1). Feeding behavior was intermediate in frequency (21 ± 3%), whereas walking and drinking had low prevalence (2.2 ± 0.4% and 1.2 ± 0.4%, respectively). The time spent in milking was only 1.5%, with an average of 2.53 milkings/d. The cows spent 62% of their lying time on their left side and 63% and 11% of their standing time idle-standing and perching, respectively. A mean of 7.3 lying bouts was observed in the video data, with 6 to 10 lying bouts/cow. Across all 5 cows, the length of the shortest observed lying bouts varied between 6.7 min and 69.2 min, and the longest varied between 101 min and 196 min.

The sensitivity, specificity, and predictive values (positive and negative) for each combination of dataset, device, and behavior are reported in Table 2. Both recording devices provided data of high sensitivity (Sen ≥ 0.961) and specificity (Sp ≥ 0.951) for lying and standing behavioral patterns, displaying predictive values close to 1.00 (PPV ≥ 0.966 and NPV ≥ 0.945). The probability of correctly predicting lying and standing behavior was near 100%. The HOBO logger displayed high sensitivity (Sen ≥ 0.991) and specificity (Sp ≥ 0.998) at the level of the recorded time unit (1 min) for laterality of lying behavior (left and right), showing predictive values close to 1.00. The IceTag device inadequately recorded walking at both frequencies of analysis (i.e., 1 s and 1 min): the sensitivity levels were low and the larger standard errors indicate a greater among-cow variability for walking than for lying and standing behavior. The probability that an IceTag recorded true walking was low (approximately 25 to 30%).

Sampling Intervals of the Automatic Recording Devices

Table 3 shows the influence of different sampling intervals on the assessment of several behavioral activities. A strong relationship ($R^2 ≥ 0.978$) was found between the total lying times from data on a per-second basis and

analyzed by $2 \times 2$ contingency tables ($TP =$ true positives, $FN =$ false negatives, $FP =$ false positives, and $TN =$ true negatives; FREQ procedure of SAS). We determined the sensitivity ($Sen = TP/(TP + FN)$; proportion of true positives that are correctly identified by the test) and specificity ($Sp = TN/(TN + FP)$; proportion of true negatives that are correctly identified by the test), treating the video recordings as the gold standard (Altman and Bland, 1994a). We calculated the positive predictive values ($PPV =$ TP/(TP + FP), and the negative predictive values ($NPV =$ TN/(TN + FN), respectively (Altman and Bland, 1994b).

Sampling Intervals of the Automatic Recording Devices. To optimize the choice of sampling intervals to obtain reliable estimates for daily behavior of the dairy cows, we created the scan samples dataset from the classified data collected by the IceTag loggers on a per-second basis (12 cows, 3 d). For this scan sample dataset, we selected data points in the logger records with 10 sampling intervals: 1 s and 1, 2, 3, 4, 5, 10, 15, 30, and 60 min. To determine lying and standing behavior and lying and standing bouts, we counted the number of consecutive data points with identical status for each sampling interval. The time that cows spent lying and standing were summarized in a daily value (h/d) to facilitate comparison between different sampling intervals. For each of the 10 sampling intervals, we determined total lying time (h/d); total standing time (h/d); number of lying bouts (bouts/d); the average, maximum, and minimum lengths of lying bouts (min/bout); and number of steps (steps/d) for each of the 12 cows, for each of the 3 d. Walking was excluded because, based on the previous results, we had determined that this behavior should not be analyzed.

The Shapiro-Wilk test revealed that the average and minimum length of lying bouts, and number of steps were not normally distributed. We applied logarithmic transformations ($\log_{10}(x)$) to achieve normal distributions (Martin and Bateson, 2007). Transformed data were analyzed by 1-way ANOVA using the General Linear Model (PROC GLM of SAS). Tukey’s studentized range test was used to determine whether differences ($P < 0.01$) existed between sampling intervals. Estimates of total lying time, number of lying bouts, the mean, maximum, and minimum lengths of lying bouts derived for each sampling interval (1, 2, 3, 4, 5, 10, 15, 30, and 60 min) were compared with estimates based on per-second data (1 s) using linear regression (PROC REG of SAS; $n =$ 12 cows, each day considered separately). Additional tests were included to evaluate whether slope = 1 and intercept = 0 ($P < 0.05$). We followed the recommendations by Ledgerwood et al. (2010), who suggested that estimates of lying and standing behaviors should meet these criteria: $R^2 ≥ 0.90$ and slope and intercept are not statistically different ($P > 0.05$) from 1 and 0, respectively.
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estimates obtained by 1, 2, 3, 4, 5, 10, and 15 min sampling intervals, with no statistical difference ($P > 0.05$) from 0 and 1 for intercept and slope, respectively. The lying time estimates generated with the 30 and 60 min sampling intervals showed a positive relationship ($R^2 \geq 0.838$), but a slope greater than 1 and an intercept significantly greater than 0 were found. A clear relationship was found between the standing times obtained from data on a per-second basis and those recorded by sampling intervals from 1 to 15 min ($R^2 \geq 0.955$; $P > 0.05$ for slope = 1, intercept = 0). The estimates for the lying times with the long sampling intervals (30 and 60 min) showed a strong relationship, but the slope and/or intercept were significantly different from 0 or 1, respectively ($P < 0.05$).

The number of lying bouts obtained by sampling interval of 1 and 2 min showed a strong correspondence ($R^2 \geq 0.921$; $P > 0.05$ for slope = 1, intercept = 0) with the values generated from sampling interval of 1 s. In contrast, long sampling intervals (15, 30, and 60 min) highlighted a poor relationship ($R^2 \leq 0.587$), underestimating the daily number of lying bouts. A similar pattern was found for the mean length of the lying bouts; sampling intervals shorter than 5 min showed a relationship $> 0.90$, whereas long sampling intervals (30 and 60 min) showed a very poor relationship ($R^2 = 0.289$ and $R^2 = 0.002$, respectively; $P < 0.05$ for slope = 1, intercept = 0). A poor relationship ($R^2 \leq 0.563$) was found between the minimum length of the lying bouts from data on a per-second basis and estimates obtained $\geq 3$ min sampling intervals and slope or intercept were significantly different ($P > 0.05$) from 0 or 1. The maximum length of the lying bouts found by short sampling intervals (< 5 min), showed no statistical difference ($P > 0.05$) from 0 and 1.

Table 1. Mean ($\mu$) and SE for the behaviors of 5 cows monitored by video recording system (VRS) and electronic recording devices (IceTag and HOBO) over the course of 24 h, with a sampling interval of 1 min.

<table>
<thead>
<tr>
<th>Behavior</th>
<th>VRS, $\mu \pm SE$</th>
<th>IceTag, $\mu \pm SE$</th>
<th>HOBO, $\mu \pm SE$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lying, h/d</td>
<td>9.05 ± 0.73</td>
<td>9.04 ± 0.73</td>
<td>9.05 ± 0.73</td>
</tr>
<tr>
<td>Right side, h/d</td>
<td>3.45 ± 1.06</td>
<td>3.43 ± 1.07</td>
<td>3.43 ± 1.07</td>
</tr>
<tr>
<td>Left side, h/d</td>
<td>5.60 ± 1.51</td>
<td>5.63 ± 1.51</td>
<td>5.63 ± 1.51</td>
</tr>
<tr>
<td>Lying bouts, bouts/d</td>
<td>7.33 ± 0.76</td>
<td>7.33 ± 0.76</td>
<td>7.27 ± 0.78</td>
</tr>
<tr>
<td>Standing, h/d</td>
<td>14.41 ± 0.70</td>
<td>14.47 ± 0.74</td>
<td>14.95 ± 0.73</td>
</tr>
<tr>
<td>Walking, h/d</td>
<td>0.54 ± 0.09</td>
<td>0.50 ± 0.05</td>
<td>0.50 ± 0.05</td>
</tr>
<tr>
<td>Steps, steps/d</td>
<td>1377 ± 332</td>
<td>1377 ± 332</td>
<td>1377 ± 332</td>
</tr>
</tbody>
</table>

$^1$HOBO Pendant G (Onset Computer Corporation, Pocasset, MA) and IceTag (IceRobotics, Edinburgh, UK).
for intercept and slope, respectively, but the coefficient of determination was ≤ 0.845.

For the steps, all sampling intervals resulted in a slope greater than 1 or an intercept significantly greater than 0, and the number of steps/d was strongly underestimated.

**DISCUSSION**

**Comparison of the Behavioral Activity Data Obtained by the Electronic Recording Devices and by the VRS**

The HOBO and IceTag devices accurately measured lying and standing behaviors in lactating dairy cows kept in a highly automated loose-housing barn. Measures of lying and standing behavior derived from the HOBO and IceTag were strongly correlated. The use of electronic data loggers to measure lying behavior has become increasingly common, as they record noninvasively and overcome the time-consuming limitations of video-based observations. The results of validation studies using video observations as a control have shown high levels of correspondence between video recording and automatic devices when considering the total duration of behavioral activities (Müller and Schrader, 2003; McGowan et al., 2007; Ledgerwood et al., 2010).

The IceTag device does not measure walking directly but assesses intensity of activity measured as percent active calculated on step basis. Walking occupied only a small percentage of time and was underestimated by the IceTag. The poor classification of walking events by the IceTag resulted in a low ability (Sen) and probability (PPV) for this behavior; it requires a more precise measuring method compared with lying and standing.

The 2 × 2 contingency tables test on behavioral data indicated that only 30% of the walking events were correctly identified by the IceTag. Direct use of the recorded number of steps per second to classify walking leads to an inaccurate prediction. The sampling rate is likely to affect the accuracy of counting steps because the peak accelerations are very brief, often occurring during a single time sample. de Passillé et al. (2010) showed that the sampling rate of 33 Hz for the triaxial accelerometers that they used in their study was close to the minimum necessary to detect gait patterns. Scheibe and Gromann (2006) used a data logger with a frequency of 100 Hz to identify different movement patterns, whereas Pastell et al. (2009) measured gait features in dairy cows with a frequency of 25 Hz, and de Mol et al. (2009) used 50 Hz to distinguish steps of dairy cows. The ability of accelerometers to identify locomotion behavior patterns increases as a function of increased sampling rate (Moreau et al., 2009). A more comprehensive algorithm supporting real time analysis of acceleration data in the 3 axes sampled at much greater sampling frequency, excluding lying periods and improving the filtering procedure, could be a more accurate way to estimate walking. In this study, to classify dairy cows as walking, we only used IceTag-

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**Table 2. Sensitivity, specificity, positive predictive value, and negative predictive value from 2 x 2 contingency tables for the correspondence of behavior observations between IceTag, HOBO Pendant G processed data, and video data; mean values and SE for 5 cows over a 24 h observation period**

<table>
<thead>
<tr>
<th>Item</th>
<th>Sensitivity (Sen), µ ± SE</th>
<th>Specificity (Sp), µ ± SE</th>
<th>Positive predictive value (PPV), µ ± SE</th>
<th>Negative predictive value (NPV), µ ± SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>IceTag–Video</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lying</td>
<td>0.997 ± 0.001</td>
<td>1.000 ± &lt; 0.001</td>
<td>0.999 ± &lt; 0.001</td>
<td>0.998 ± &lt; 0.001</td>
</tr>
<tr>
<td>Standing</td>
<td>0.977 ± 0.004</td>
<td>0.951 ± 0.006</td>
<td>0.966 ± 0.004</td>
<td>0.967 ± 0.006</td>
</tr>
<tr>
<td>Walking</td>
<td>0.291 ± 0.012</td>
<td>0.982 ± 0.002</td>
<td>0.303 ± 0.037</td>
<td>0.982 ± 0.002</td>
</tr>
<tr>
<td>IceTag–Video</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lying</td>
<td>0.997 ± &lt; 0.001</td>
<td>1.000 ± 0.000</td>
<td>1.000 ± 0.000</td>
<td>0.998 ± &lt; 0.001</td>
</tr>
<tr>
<td>Standing</td>
<td>0.969 ± 0.005</td>
<td>0.995 ± 0.001</td>
<td>0.996 ± 0.001</td>
<td>0.958 ± 0.006</td>
</tr>
<tr>
<td>Walking</td>
<td>0.264 ± 0.022</td>
<td>0.979 ± 0.002</td>
<td>0.237 ± 0.037</td>
<td>0.982 ± 0.003</td>
</tr>
<tr>
<td>HOBO–Video</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lying</td>
<td>0.990 ± 0.004</td>
<td>0.996 ± &lt; 0.001</td>
<td>0.994 ± 0.001</td>
<td>0.993 ± 0.002</td>
</tr>
<tr>
<td>Laterality (right)</td>
<td>0.991 ± &lt; 0.001</td>
<td>0.998 ± 0.001</td>
<td>0.993 ± 0.001</td>
<td>0.997 ± 0.001</td>
</tr>
<tr>
<td>Laterality (left)</td>
<td>0.993 ± 0.003</td>
<td>0.999 ± &lt; 0.001</td>
<td>0.994 ± 0.002</td>
<td>0.997 ± &lt; 0.001</td>
</tr>
<tr>
<td>Standing</td>
<td>0.996 ± &lt; 0.001</td>
<td>0.986 ± 0.008</td>
<td>0.990 ± 0.004</td>
<td>0.994 ± 0.001</td>
</tr>
<tr>
<td>IceTag–HOBO 4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lying</td>
<td>0.993 ± 0.001</td>
<td>0.994 ± 0.002</td>
<td>0.992 ± 0.004</td>
<td>0.995 ± &lt; 0.001</td>
</tr>
<tr>
<td>Standing</td>
<td>0.961 ± 0.003</td>
<td>0.991 ± 0.002</td>
<td>0.994 ± 0.001</td>
<td>0.945 ± 0.004</td>
</tr>
</tbody>
</table>

1HOBO Pendant G (Onset Computer Corporation, Pocasset, MA) and IceTag (IceRobotics, Edinburgh, UK).
2With a 1-s frequency– number of observations 432,000.
3With a 1-min frequency– number of observations 7200.
4With a 1-min frequency, HOBO Pendant G as gold standard– number of observations 7200.
recorded percentage threshold for calves (A_P ≥ 50% of recorded time) reported by Trénel et al. (2009).

The HOBO logger can accurately describe the laterality of lying behavior, as previously demonstrated by Ledgerwood et al. (2010). Rumen fill, rumination, eating, and physiological state (particularly stage of pregnancy, size of the calf, and cannulation) influence the laterality of lying behavior (Arave and Walters, 1980; Grant et al., 1990; Forsberg et al., 2008; Tucker et al., 2009), suggesting that pronounced laterality may indicate discomfort. The 5 cows monitored by HOBO logger spent more than 60% of the 72 h of the study on their left side, but with a wide variation between cows (1 cow spent 100% of lying time on the left side, whereas another individual spent 23% of lying time on the left side). Automated measurement of this aspect of lying behavior may elucidate the role of laterality as an indicator of cow comfort and might be useful for assessing the welfare of dairy cattle, particularly when uncomfortable stall conditions exist (Tucker et al., 2009).

Video recording systems compared with current data loggers provide a more complete view of all behaviors and also of the location of the cows in the barn, but processing this information is time consuming and labor intensive. In this study, the time that a trained observer needed to analyze the behavior of 1 cow for 24 h was 8.4 h, compared with only a few minutes by these data loggers. However, the choice of a system to monitor behavior is not only influenced by the time and labor required but also by the objectives of the particular study, the type and structure of the experiment, and economic factors. Combining behavioral monitoring with other sources of information (such as from VMS) may be help-

### Table 3. Influence of different sampling intervals on behavioral activity assessments; means, SEM, Tukey's studentized range test, relationship (\(R^2\)) and significance of the slope and intercept differed from 1 and 0 for each behavioral activity recorded by data loggers (IceTag\(^2\)) with different sampling intervals for 12 cows over a 3-d observation period\(^3\),\(^4\)

<table>
<thead>
<tr>
<th>Item</th>
<th>Sampling interval</th>
<th>1 s</th>
<th>1 min</th>
<th>2 min</th>
<th>3 min</th>
<th>4 min</th>
<th>5 min</th>
<th>10 min</th>
<th>15 min</th>
<th>30 min</th>
<th>60 min</th>
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<tr>
<td>Time lying, h/d</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>10.94(a)</td>
<td>10.94(a)</td>
<td>10.95(a)</td>
<td>10.95(a)</td>
<td>10.93(a)</td>
<td>10.91(a)</td>
<td>10.90(a)</td>
<td>10.90(a)</td>
<td>10.87(a)</td>
<td>10.78(a)</td>
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</tr>
<tr>
<td>SEM</td>
<td>0.324</td>
<td>0.325</td>
<td>0.325</td>
<td>0.324</td>
<td>0.324</td>
<td>0.330</td>
<td>0.329</td>
<td>0.334</td>
<td>0.351</td>
<td>0.405</td>
<td></td>
</tr>
<tr>
<td>(R^2)</td>
<td>–</td>
<td>1.000</td>
<td>1.000</td>
<td>0.999</td>
<td>0.998</td>
<td>0.997</td>
<td>0.993</td>
<td>0.978</td>
<td>0.959*</td>
<td>0.838*</td>
<td></td>
</tr>
<tr>
<td>Time standing, h/d</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Mean</td>
<td>12.60(a)</td>
<td>12.60(a)</td>
<td>12.61(a)</td>
<td>12.58(a)</td>
<td>12.63(a)</td>
<td>12.62(a)</td>
<td>12.70(a)</td>
<td>12.70(a)</td>
<td>12.54(a)</td>
<td>12.64(a)</td>
<td>12.89(a)</td>
</tr>
<tr>
<td>SEM</td>
<td>0.325</td>
<td>0.326</td>
<td>0.329</td>
<td>0.326</td>
<td>0.331</td>
<td>0.330</td>
<td>0.337</td>
<td>0.337</td>
<td>0.337</td>
<td>0.349</td>
<td>0.377</td>
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<tr>
<td>(R^2)</td>
<td>–</td>
<td>0.998</td>
<td>0.995</td>
<td>0.995</td>
<td>0.992</td>
<td>0.986</td>
<td>0.972</td>
<td>0.972</td>
<td>0.955</td>
<td>0.906*</td>
<td>0.774*</td>
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<tr>
<td>Lying bouts, bouts/d</td>
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<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Mean</td>
<td>9.81(a)</td>
<td>9.58(ab)</td>
<td>9.19(ab)</td>
<td>8.94(ab)</td>
<td>8.61(abc)</td>
<td>8.33(bc)</td>
<td>7.56(cd)</td>
<td>6.78(de)</td>
<td>5.75(e)</td>
<td>4.75f</td>
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<tr>
<td>SEM</td>
<td>0.647</td>
<td>0.619</td>
<td>0.592</td>
<td>0.587</td>
<td>0.548</td>
<td>0.533</td>
<td>0.494</td>
<td>0.410</td>
<td>0.277</td>
<td>0.227</td>
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<tr>
<td>(R^2)</td>
<td>–</td>
<td>0.982</td>
<td>0.921</td>
<td>0.899</td>
<td>0.826</td>
<td>0.819</td>
<td>0.722</td>
<td>0.587</td>
<td>0.358</td>
<td>0.052*</td>
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<tr>
<td>Mean length of lying bout, min/bout</td>
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<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Mean</td>
<td>78.42(a)</td>
<td>79.69(ab)</td>
<td>82.61(ab)</td>
<td>85.16(ab)</td>
<td>86.76(ab)</td>
<td>89.44(bc)</td>
<td>96.82(bc)</td>
<td>106.98(cd)</td>
<td>122.37(de)</td>
<td>146.68(e)</td>
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</tr>
<tr>
<td>(R^2)</td>
<td>–</td>
<td>0.993</td>
<td>0.965</td>
<td>0.934</td>
<td>0.902</td>
<td>0.879</td>
<td>0.784</td>
<td>0.626</td>
<td>0.289*</td>
<td>0.002*</td>
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</tr>
<tr>
<td>Maximum length of lying bout, min/bout</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>152.98(a)</td>
<td>157.06(b)</td>
<td>160.44(c)</td>
<td>159.08(a)</td>
<td>163.67(a)</td>
<td>167.64(ab)</td>
<td>175.00(abc)</td>
<td>195.42(bc)</td>
<td>202.50(c)</td>
<td>238.33(d)</td>
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<tr>
<td>(R^2)</td>
<td>–</td>
<td>0.845</td>
<td>0.813</td>
<td>0.820</td>
<td>0.694</td>
<td>0.700*</td>
<td>0.627*</td>
<td>0.284*</td>
<td>0.250*</td>
<td>0.060*</td>
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<tr>
<td>Minimum length of lying bout, min/bout</td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
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<tr>
<td>Mean</td>
<td>21.12(a)</td>
<td>21.36(a)</td>
<td>21.67(a)</td>
<td>27.92(abc)</td>
<td>27.33(bc)</td>
<td>29.58(cd)</td>
<td>35.06(de)</td>
<td>44.17(ef)</td>
<td>55.83(fg)</td>
<td>78.33(g)</td>
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<tr>
<td>SEM</td>
<td>4.555</td>
<td>4.523</td>
<td>4.524</td>
<td>5.276</td>
<td>5.098</td>
<td>5.146</td>
<td>4.428</td>
<td>4.51</td>
<td>4.653</td>
<td>5.767</td>
<td></td>
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<tr>
<td>(R^2)</td>
<td>–</td>
<td>0.998</td>
<td>0.996</td>
<td>0.563*</td>
<td>0.564*</td>
<td>0.528*</td>
<td>0.572*</td>
<td>0.342*</td>
<td>0.137*</td>
<td>0.015*</td>
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</tr>
<tr>
<td>Steps, steps/d</td>
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<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Mean</td>
<td>1499.97(a)</td>
<td>24.78(b)</td>
<td>12.03(c)</td>
<td>8.67(cd)</td>
<td>5.92(de)</td>
<td>5.00(e)</td>
<td>2.25(f)</td>
<td>1.86(f)</td>
<td>0.89(g)</td>
<td>0.28(g)</td>
<td></td>
</tr>
<tr>
<td>SEM</td>
<td>96.176</td>
<td>1.863</td>
<td>0.966</td>
<td>0.697</td>
<td>0.519</td>
<td>0.512</td>
<td>0.283</td>
<td>0.279</td>
<td>0.177</td>
<td>0.094</td>
<td></td>
</tr>
<tr>
<td>(R^2)</td>
<td>–</td>
<td>0.765*</td>
<td>0.646*</td>
<td>0.646*</td>
<td>0.564*</td>
<td>0.419*</td>
<td>0.249*</td>
<td>0.153*</td>
<td>0.113*</td>
<td>0.024*</td>
<td></td>
</tr>
</tbody>
</table>

\(a\)–\(g\) Means within the same row with the same letter are not significantly different (\(P < 0.01\)).

\(1\) Slope and intercept were significant different (*\(P < 0.05\)) from 1 and 0, respectively.

\(2\) IceTag (IceRobotics, Edinburgh, UK).

\(3\) Means are presented as untransformed means.

\(4\) Analyses were on log-transformed data.
ful for improving the quality and interpretation of daily cow behavior data (Liberati and Zappavigna, 2009).

**Sampling Intervals of the Automatic Recording Devices**

Each sampling interval should be carefully selected based on the objectives of the particular study and the behavior that is to be examined. The results of the current study show that sampling intervals with relatively short lengths (from 1 to 15 min) were accurate and precise for measuring the daily amount of time spent lying and standing, in agreement with previous studies of beef cattle (Mitlöchner et al., 2001) and dairy cows (Mattachini et al., 2011). Although the long sampling intervals (e.g., 30 and 60 min) showed a positive relationship for estimating the time spent lying and standing, they were inappropriate because they lacked accuracy and precision in predicting these behaviors.

The number of lying bouts estimated by the logger with sampling intervals of 1 and 2 min was strongly correlated to values generated with intervals of 1 s. Long sampling intervals (> 2 min) were inappropriate for predicting the number of lying bouts during the day. Short bouts (≤ 2 min) were missed by longer sampling intervals. Ledgerwood et al. (2010) showed that shorter intervals between samples (≤ 30 s) are required to accurately measure the time spent lying and standing, in agreement with previous studies of beef cattle (Mitlöchner et al., 2001) and dairy cows (Mattachini et al., 2011). Although the long sampling intervals (e.g., 30 and 60 min) showed a positive relationship for estimating the time spent lying and standing, they were inappropriate because they lacked accuracy and precision in predicting these behaviors.

The number of lying bouts estimated by the logger with sampling intervals of 1 and 2 min was strongly correlated to values generated with intervals of 1 s. Long sampling intervals (> 2 min) were inappropriate for predicting the number of lying bouts during the day. Short bouts (≤ 2 min) were missed by longer sampling intervals. Ledgerwood et al. (2010) showed that shorter intervals between samples (≤ 30 s) are required to accurately measure the number of lying bouts, particularly if lying and standing bouts are very short. The relationship between short sampling intervals and lying bouts (duration and number) may be explained, in part, by a relatively low percentage of short (≤ 2 min) lying bouts—in the current study < 0.1% of the total lying time and < 3.5% of the total lying bouts (data not shown, obtained from filtered per-second data recorded with IceTag). The lying bouts, and in particular the proportion of short lying bouts, are affected by several factors such as age, stage of lactation, housing design, and management factors. For these reasons, to measure the number of lying bouts, the use of sampling intervals less than 2 min is recommended. Application of the filtering methods (event criterion; ≤ 25 s data, and ≤ 2 min data) in the current study reduced the number of lying bouts considerably and improved the estimates, but the effects on estimated total daily lying time were minor, in particular for the per-second dataset (data not shown). As reported by Trénel et al. (2009), the filtering method may have improved the information yield from the loggers considerably by providing valid information on the number and durations of lying and standing events in comparison with unfiltered data. Sampling interval and filtering method are closely related and together may have affected the accuracy of the information generated by the IceTag and the HOBO Pendant G.

Determining optimum settings for the device is critical before applying it in the field, as these modifications impact effective battery and memory life. Sampling interval should be both effective and efficient. Time constraints, the treatments, their duration, the research questions, and the features and specifications of the data logger play a role in selecting the interval. The type and quality of the data logger will affect the resolution and amount of data that can be obtained.

In conclusion, the IceTag and the HOBO Pendant G are time- and labor-saving tools that improve awareness of cow comfort related to lying behavior. Reliable estimates of lying and standing time can be generated using less frequent sampling intervals (e.g., 10 min or 15 min). Shorter sampling intervals (≤ 2 min) are required to accurately measure all aspects of lying behavior and especially to estimate the number and duration of lying bouts. Further development of data loggers will facilitate the collection of information about dairy cow activity, which may improve automatic livestock management systems for the efficient monitoring and control of modern automated dairy farms.

**LITERATURE CITED**


