Technical note: A comparison of editing criteria for lying-behaviour data derived from three-dimensional accelerometer devices on grazing dairy cows

SJ Hendriks[a]*, CVC Phyn[b], S-A Turner[b,c], KR Mueller[d], B Kuhn-Sherlock[b], DJ Donaghy[a], JM Huzzey[e] and JR Roche[b,f,g]

[a]School of Agriculture and Environment, Massey University, Palmerston North 4410, New Zealand; [b]DairyNZ Ltd., Hamilton 3240, New Zealand; [c]Current address: Dairy Goat Co-operative, PO Box 1398, Hamilton 3240, New Zealand; [d]School of Veterinary Sciences, Massey University, Palmerston North 4410, New Zealand; [e]California Polytechnic State University, Department of Animal Science, San Luis Obispo, CA 93407; [f]School of Biological Sciences, University of Auckland, Private Bag 92019, Auckland 1142, New Zealand; [g]Current address: Ministry for Primary Industries, Wellington 6140, New Zealand

**Corresponding author:* Email: s.hendriks@massey.ac.nz

Abstract

Shorter, more-frequent lying bouts (LB) could be used to predict calving and as an indicator of animal discomfort and ill-health. In this technical study, we reviewed the literature to describe criteria for removing false short LB, caused by minor movements, from accelerometer data using IceRobotics technology. Using an existing dataset of grazing cows, we compared unedited with edited accelerometer data after applying three different LB thresholds (LB <33 s, ≤2 min, and <4 min were removed) within IceQube and IceTag accelerometers. Daily lying time, LB (no./d) and LB duration were derived from either IceQube or IceTag devices for 146 and 159 multiparous cows, respectively. Very-short LB were more common in IceTag than IceQube data. Applying a shorter LB criterion (<33 s) to the IceQube dataset produced minimal differences between unedited (8.8±3.6 no./d; n=64,512 lying records) and edited data (8.3±3.4 no./d; n=60,463). In contrast, we observed large differences between unedited (307±293 no./d; n=2,305,693) and edited data (8.8±4.1 no./d; n=66,139) when a longer LB criterion (≤2 min) was applied to the IceTag dataset. Removing short LB that are unlikely to represent true behaviour will improve the interpretation of lying behaviour data; however, prospective studies are needed to determine the most-suitable LB criterion.

Keywords: lying behaviour; grazing cows; accelerometer

Introduction

Activity monitoring devices that measure cow behaviour may allow remote and individualised management of animals and improved dairy cow health and welfare. However, it is important that the methodology chosen to edit behaviour data is supported by an appropriate and robust validation study, where a high level of accuracy is reported (Charlton et al. 2017). Several studies indicate that unedited data from IceTag and IceQube accelerometer devices (IceRobotics Ltd., Edinburgh, Scotland) provide accurate records of daily lying time in cattle across a range of systems (Mattachini et al. 2013; McGowan et al. 2007; Ungar et al. 2018), but there is inconsistency in the literature regarding the appropriateness of editing criteria for lying bouts (LB), which are a potentially valuable indicator of cow health, welfare and comfort.

Lying bouts can be defined as the period of lying between two standing events and can be short in duration; therefore, a high sampling frequency is required to capture LB accurately. However, this creates a dichotomy because a high sampling frequency will also detect minor movements, such as kicking or scratching, which generate short LB (e.g., <4 min) in the dataset that are not reflective of true lying behaviour (Mattachini et al. 2013). These short LB are a systematic error and should be discarded to improve data accuracy. However, there is no consensus for a LB editing protocol that researchers can follow when analysing and interpreting lying-behaviour data from IceRobotics accelerometer devices.

We are interested in examining lying behaviours in grazing dairy cows during the transition period from late gestation to early lactation when animals are at greatest risk of adverse health events. To our knowledge, no researchers validating IceRobotics devices in grazing cows have recommended the removal of false LB from the dataset. We expect that data derived from IceRobotics devices will contain short LB that are unlikely to be representative of true behaviour, as reported in housed cows, and will need to be discarded (Kok et al. 2015). Therefore, our first objective was to review published experiments that have validated IceRobotics devices to assess criteria used for editing behavioural data prior to analysis. Our second objective was to use an existing dataset from transition dairy cows grazing pasture to retrospectively examine descriptive lying behaviour data before and after applying editing criteria, and to justify the selection of the final criteria for subsequent research.

Literature review

We reviewed the published literature for studies that used either the IceQube or IceTag device manufactured by IceRobotics Ltd. (Edinburgh, Scotland). The IceQube and IceTag should be considered separately when determining an appropriate experimental methodology due to their different sampling frequencies (4 and 16 Hz, respectively). We first reviewed studies that have used either device in grazing cows to evaluate editing criteria applied. Second, we reviewed studies validating either device to evaluate the experimental design and editing methodologies. Due to our interest in using both lying time and LB behaviour derived from IceQube and IceTag devices, we focused specifically on studies that validated both behaviours.

Few studies undertaken in grazing cows or in cows with access to pasture have examined both lying time and LB using IceTag devices and our literature search returned no studies using IceQube devices. One study in grazing cows (Umstatter et al. 2015) and two studies in which cows had access to pasture (Black & Krawczel 2016; Rice et al. 2017) determined lying time and LB; however, there was no single preferred method for managing the data. For example, Umstatter et al. (2015) discarded LB <4 min as recommended by Tolkamp et al. (2010), while others discarded LB ≤2 min, as recommended by Munksgaard et al. (2006), Endres & Barberg (2007), and Bewley et al. (2010). While most researchers removed LB ≤2 min, the justification for this editing criteria was not based on validation studies (e.g., Endres & Barberg 2007, Bewley et al. 2010) or the study did not provide a detailed description of the experimental design (e.g., Munksgaard et al. 2006).

Variation in the time animals spend engaged in certain lying and standing behaviours under different systems can affect the outcome of the validation study; therefore, validation studies undertaken under similar conditions are preferred when determining the most appropriate editing methodology for subsequent research (Kok et al. 2015; Ledgerwood et al. 2010). Only one study, however, has validated both lying time and LB behaviour derived from IceTag devices in dairy cows grazing pasture (McGowan et al. 2007). Others have validated both behaviours from IceQube (Charlton et al. 2017) and IceTag devices in cows housed indoors and taken out to pasture between morning and afternoon milking (Rutter et al. 2014); but these studies have limitations. McGowan et al. (2007) reported that the unedited dataset recorded by the IceTag provided accurate lying time and LB values; however, the short data collection period (3 d; ~9.3 h recorded data in total), the timing of the study (during the dry period), and small sample size (n=15) may have limited the variation within the test dataset and, in particular, its applicability to the lactating cow. In comparison, according to Rutter et al. (2014), LB behaviour derived from the IceTag was grossly overestimated; however, the gold standard measure of manual behaviour records used to validate the IceTag was inadequate due to the low recording resolution (5-min intervals). Furthermore, Charlton et al. (2017) validated the IceQube, but did not report appropriate accuracy measures suggested by others (e.g., sensitivity and specificity estimates or Lin's concordance correlation; Watson & Petrie 2010). Contradictory reports exist, where Rutter et al. (2014) advised caution when interpreting the number of LB derived from unedited data from IceTag devices in cows at pasture, but authors of two other studies concluded that the original unedited data from the devices gave accurate lying time and LB records (McGowan et al. 2007; Charlton et al. 2017).

Due to these contrasting recommendations and the limitations of studies in pastured cows, we then considered validation studies undertaken in housed cows, which have more robust methodologies (e.g., Ledgerwood et al. 2010; Mattachini et al. 2013). Mattachini et al. (2013) and Tolkamp et al. (2010) both reported good correspondence between the IceTag device and continuous video observations for lying time and LB, but differed in their editing criteria, recommending the removal of LB ≤2 min and <4 min, respectively. For the IceQube device, to our knowledge, only one validation study has reported lying time and LB measures, with authors recommending the removal of LB <33 s from the original data (Kok et al. 2015).

Based on our assessment of the literature, we chose LB editing criteria of <33 s, ≤2 min, and <4 min from previous validation studies to conduct our next phase of this study. We visually inspected our existing accelerometer dataset of transition dairy cows grazing pasture before and after applying the three different editing criteria to examine the within-device variability for IceQube and IceTag devices when short LB are removed.

Comparison of three editing criteria
Materials and methods

Description of dataset. A database, described in detail by Hendriks et al. (2019) was compiled from four separate parent experiments that investigated various management- and cow-related factors during the transition period in clinically-healthy grazing cows. Of 380 cows available from the four experiments, data from 311 multiparous mixed-age and breed (Holstein-Friesian, n=216; Holstein-Friesian x Jersey, n=93; and Jersey, n=1) cows were selected for analysis. In total, 69 cows were removed from the analysis due to incomplete data [>10 d of data missing between –5 to +10 d relative to the day of calving (d 0)], inaccessible files, the device fell off during the experimental period, or the cow was removed from the study.

Behaviour data collection and editing. Each cow was fitted with one device, either an IceQube (n=146) or IceTag (n=159) on the lateral side of a hind leg. No effect of hind limb choice for sensor attachment on lying behaviour has been reported (Munksgaard et al. 2006). IceQube and IceTag devices were equally spread across treatments within parent experiment. Both devices were contained within plastic housing secured by a leg bracelet (IceRobotics Ltd.) and captured data at a frequency of 4 Hz (IceQube) and 16 Hz (IceTag).

Through the position of the three axes of the devices, behavioural parameters were characterised. Lying behaviour was recorded when the orientation of the hind leg was horizontal and LB were defined as periods between the device changing from vertical to horizontal and back to vertical. These data were stored on the device (60 d on-board storage capacity) with data granularity at a sampling interval of one second. Data were removed and downloaded using the IceManager 2010 software (IceRobotics Ltd.) to generate a summary file containing all recorded LB, with a start date, start time (hh:mm:ss), and duration (s) and this was used to calculate daily LB (no./d) and mean LB duration (min/d). From the output dataset, the sampling dates for each individual cow were assigned an experimental day (expday) relative to d 0. Each cow's recording period began at 00:00 on the day following attachment, as recommended by Bewley et al. (2010). This transformed dataset was the basis of subsequent analyses.

Statistical analysis. Statistical analyses were undertaken using SAS version 9.4 (SAS Institute Inc., Cary, NC). Recorded data ranged from –40 to +162 d (mean ± standard deviation (SD); start expday = –19 ± 13 d and end expday = 43 ± 35 d). Using PROC FREQ, the number of daily behaviour records per cow was determined and expday were discarded where data from fewer than 100 cows and two studies were available. The remaining data included 14,891 records from 305 cows during the period –21 to +35 d. Lying time was calculated within expday by summation of LB durations for individual cows using PROC SUMMARY. Daily LB were calculated using the number of observations (n) output for individual cows within expday using PROC SUMMARY and mean LB duration was calculated using the means statement in PROC SUMMARY to average the durations of all LB for individual cows within expday.

Based on the literature review, three different LB criteria were applied to this organised dataset where LB <33 s, ≤2 min, and <4 min were discarded. To compare behaviour values from the original data and the edited data, mean, SD, and 95% confidence intervals (CI) were calculated for daily lying time, LB, and LB duration using PROC SUMMARY for the period –21 to +35 d for the two devices (Table 1). Confidence intervals were examined to determine differences at P <0.05 between editing criteria.

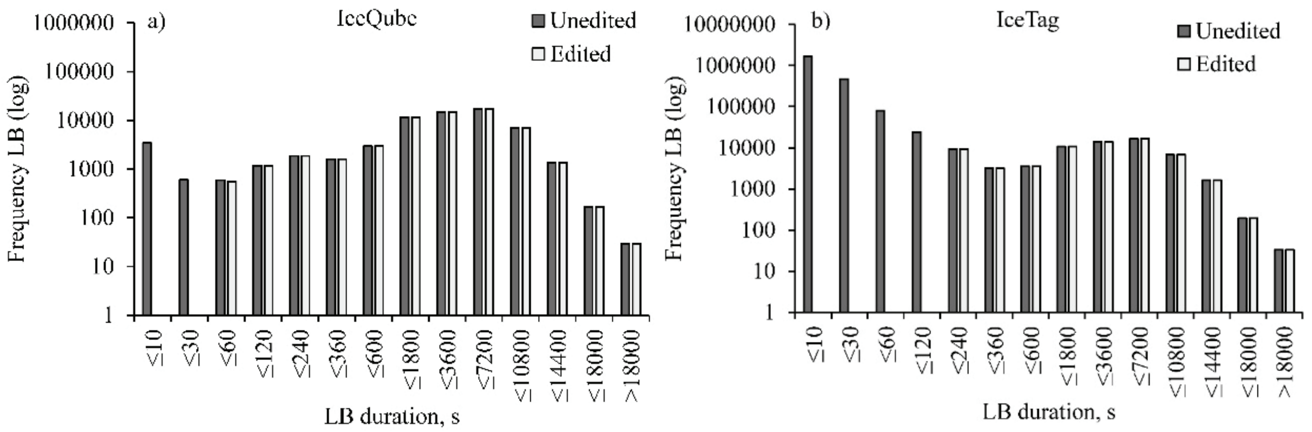
Results and discussion

Activity devices, such as those manufactured by IceRobotics Ltd., generate useful data that can be used to monitor cow behaviour; however, short false LB may overstate the lying behaviour recorded by these devices (Kok et al. 2015). As such, data editing may be necessary to improve the accuracy of the data (Mattachini et al. 2010). Mean daily lying time and LB number and duration before and after applying different LB criteria to our dataset are presented in Table 1. In the unedited data, the IceTag had 36 times more lying records than did the IceQube, indicating a very large number of short LB. Consequently, the mean daily lying time was 0.43 h greater in the IceTag than in the IceQube device; however, both devices had mean values within the range (7.50 to 10.3 h/d) of lying times previously reported for healthy grazing dairy cows (Sepúlveda-Varas et al. 2014) and cows on pasture and fed total mixed ration (Black & Krawczel 2016; Rice et al. 2017). There was no change in mean, SD, and 95% CI for daily lying time after the removal of short LB from the IceQube dataset using the three editing criteria, but mean daily lying time was reduced (by between 0.58 and 0.82 h/d) in the IceTag dataset after editing. Mean daily lying time for the IceTag dataset was shortest when LB ≤2 or <4 min were removed. False LB typically make up a small proportion of total lying time; for example, in the study by Ungar et al. (2018) removing LB ≤1 min eliminated 95% of the LB from the original data, however, LB ≤1 min only accounted for 3% of total lying time. Our results are consistent with reports that discrepancies between unedited data recorded by IceQube devices and direct observations are small when summarising daily totals for lying time (Ledgerwood et al.

Table 1 Number of records (n), mean, standard deviation (SD) and lower and upper 95% confidence limits for the daily lying time (h/d), lying bouts (LB; no./d), and LB duration (min) in grazing dairy cows for the period –21 to +35 d relative to the day of calving (d 0) wearing either IceQube or IceTag accelerometers (IceRobotics Ltd., Edinburgh, Scotland). Data are presented as original unedited data and as three subsets of edited data where different criteria were applied to the original dataset to remove LB <33 s, ≤2, and <4 min.

	IceQube					IceTag				
				95% Confidence Limits					95% Confidence Limits	
	n	mean	SD	Lower	Upper	n	mean	SD	Lower	Upper
Unedited data										
Lying time (h/d)	64,512	8.52	2.41	8.48	8.57	2,305,693	8.95	2.60	8.90	9.00
LB (no./d)	64,512	8.80	3.62	8.74	8.87	2,305,693	304	293	299	310
LB duration (min)	64,512	58.1	51.2	57.7	58.4	2,305,693	1.76	12.9	1.75	1.78
LB <33 s discarded										
Lying time (h/d)	60,463	8.52	2.41	8.48	8.57	157,200	8.37	2.41	8.32	8.41
LB (no./d)	60,463	8.25	3.39	8.19	8.32	157,200	20.8	21.5	20.4	21.2
LB duration (min)	60,463	62.0	50.6	61.6	62.3	157,200	24.1	43.5	24.0	24.3
LB ≤2 min discarded										
Lying time (h/d)	58,739	8.52	2.41	8.47	8.56	66,139	8.19	2.40	8.14	8.23
LB (no./d)	58,739	8.02	3.02	7.96	8.08	66,139	8.75	4.05	8.67	8.82
LB duration (min)	58,739	63.7	50.2	63.4	64.1	66,139	56.2	52.2	55.8	56.5
LB <4 min discarded										
Lying time (h/d)	56,887	8.50	2.41	8.46	8.55	56,866	8.13	2.40	8.09	8.18
LB (no./d)	56,887	7.77	2.72	7.71	7.82	56,866	7.52	2.77	7.47	7.57
LB duration (min)	56,887	65.7	49.8	65.4	66.1	56,866	64.9	51.3	64.5	65.2

Figure 1 Frequency (logarithmic scale) of lying bouts (LB) within a range of bout durations (between ≤10 s to >18,000 s) from unedited and edited data from IceQube (a) and IceTag (b) devices attached to transition dairy cows grazing pasture. To generate the edited datasets, LB <33 s and LB ≤120 s were removed from IceQube and IceTag datasets, respectively. Each cow was fitted with one device, either an IceQube or IceTag.



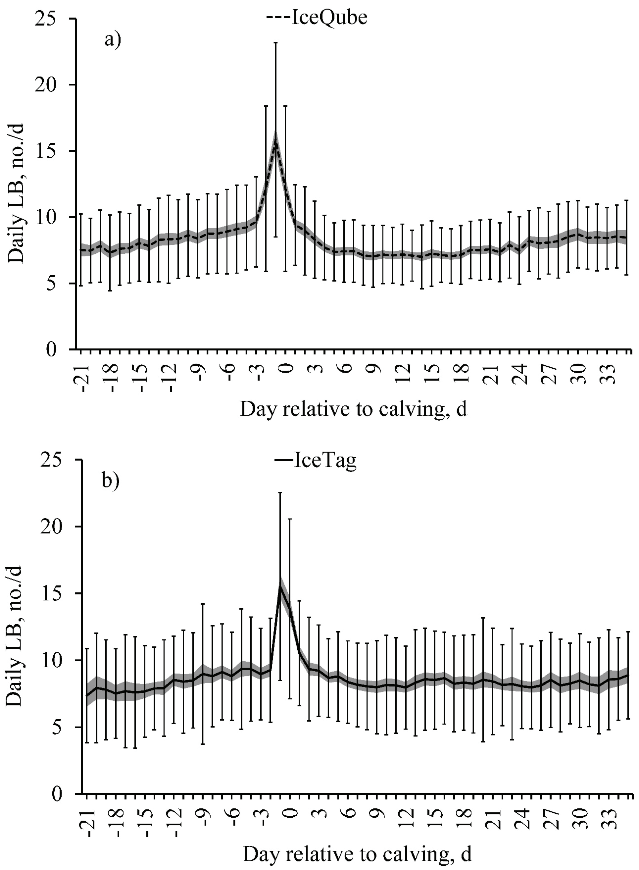
2010), and therefore, applying LB criteria has little to no effect on daily lying time as reported previously (Kok et al. 2015). Larger discrepancies in the daily lying times in the IceTag datasets after editing indicates that short LB make up a larger proportion of total lying time, which may lead to overestimation in unedited data.

In contrast, data editing using LB thresholds can substantially improve accuracy when estimating daily LB number and duration (Kok et al. 2015; Ledgerwood et al. 2010). Mean daily LB number decreased and duration increased for the IceQube dataset when each successive LB criterion was applied; however, these changes were small compared with the large differences obtained when editing IceTag data (Table 1). In total, 11.8% of the LB records from the IceQube had a duration <4 min (Fig. 1a). When LB <33 s were discarded from the IceQube data, 5.6% more LB were retained compared with the LB criteria of <4 min. Kok et al. (2015) validated the IceQube by comparing sensors on each hind limb and reported that despite relatively few LB records with a duration <4 min (7.2%), about half of those were assumed to be true LB and a LB criteria of <33 s retained 2.5% more records than a LB criteria of <4 min. Removal of LB <33 s improved combined sensitivity and specificity estimates (Se=99.3%; Sp=97.7%) relative to removing LB <4 min (Se=96.7%; Sp=100%) due to the underestimation of up to 10 LB per d using a LB criteria of <4 min (Kok et al. 2015). Therefore, based on the interpretation of our data and the recommendation of Kok et al. (2015), the use of the <33-s LB criterion in the IceQube device is our preferred option.

The frequency distribution of IceTag data was comprised of two peaks, with a left-skewed distribution of very large numbers of LB ≤240 s (≤4 min; Fig. 1b). The removal of LB <33 s, ≤2 min, and <4 min eliminated 93%, 97%, and 97.5% of LB records, respectively (Table 1). Hence, short LB made up a considerable number of the LB records in the unedited IceTag data, and although we cannot be certain from our data, it is unlikely that all of these records represented true LB (Tolkamp et al. 2010). Large numbers of erroneous short LB recorded by the IceTag may be explained, in part, by its high sampling frequency resulting in the detection of rapid behaviours and minor movements such as scratching and stepping.

It is more realistic to choose a LB criterion that is likely to represent true behaviour; therefore, we have justified our selected criteria based on LB values reported in literature. Discarding LB <33 s from our IceTag dataset (Table 1) still resulted in mean daily LB well outside of previously reported ranges of 9.5 to 13.1 no./d (Borchers et al. 2017; Calderon & Cook 2011), indicating that a higher threshold was required. Removing LB ≤2 min or <4 min in the IceTag dataset resulted in 58 and 64% fewer total lying records, respectively, compared with removing LB <33 s (Table 1). Although, when a criterion of removing LB ≤2 min was used relative to <4 min, the mean and SD for daily LB number and durations were different between these editing criteria. A validation study of IceTag devices indicated that removing LB <4 min increased accuracy, where only 2% of the LB in the final data were false (Tolkamp et al. 2010); however, that study was undertaken in housed beef cows during late pregnancy, so care should be taken when extrapolating these results to transition dairy cows grazing pasture. The authors did not recommend a shorter LB criterion because they did not record LB <4 min through video observation. However, others have reported that lactating dairy cows can spend <4 min lying in a single bout (Kok et al. 2015; Mattachini et al. 2013). Furthermore, studies undertaken in housed lactating cows using IceTag (Mattachini et al. 2013) and HOBO devices (Onset Computer Corporation, Pocasset, MA; Ledgerwood et al. 2010), which have a similar sampling frequency, support the removal of LB ≤2 min. A suitable

Figure 2 Profile of mean daily lying bouts (LB; no./d) in grazing dairy cows during the period –21 to +35 d relative to the day of calving (d 0) where LB <33 s and ≤2 min were removed from the IceQube (a) and IceTag (b) datasets, respectively. Each cow was fitted with one device, either an IceQube or IceTag. Error bars represent ± 1 standard deviation and grey shaded areas represent 95% confidence intervals around the mean.



editing criterion should maximise the true records retained as well as minimise false records to ensure data accurately reflects lying behaviour (Kok et al. 2015). It is possible for our data to contain true short LB <4 min, particularly during calving; therefore, the removal of LB ≤2 min is our preferred criterion for the IceTag dataset, to limit the risk of excluding true short LB durations.

Visual comparison of the temporal profile of daily LB number over the transition period between IceQube and IceTag devices with LB <33 s and ≤2 min removed, respectively, indicates a similar number of LB were achieved across the two devices (Fig. 2a and b). It is evident from our data that the use of different LB editing criteria can have considerable effects on the output data of these devices (Fig. 1). Based on our study, we cannot determine whether the editing criteria chosen, represented cow lying behaviour at the same level of accuracy that has been reported in validation studies and the application of these editing criteria under different conditions to which they were tested is a limitation of our study; however, the final editing criteria chosen produced descriptive data that were consistent with previous literature and were biologically plausible.

Further investigations are required to determine inter-device agreement and the precision of accelerometer-derived data relative to true lying behaviours. Therefore, we recommend that future validation studies use an appropriate and robust experimental protocol, which considers potentially false LB, to test the accuracy, sensitivity and specificity of IceTag and IceQube devices for recording lying behaviour in grazing cows.

Conclusions

Short LB that are unlikely to represent true behaviour in the original data recorded by IceQube and IceTag devices biases the number and duration of daily LB derived, but without materially affecting daily mean lying time for IceQube devices. Using previous reports validating IceQube and IceTag devices, along with an assessment of our own dataset from transition cows grazing pasture, we chose from three editing criteria where LB <33 s, ≤2 min, and <4 min were discarded from the original data recorded by IceRobotics devices. Removing LB <33 s and ≤2 min from the data recorded by the IceQube and IceTag devices, respectively, was our preferred option. The removal of LB using these criteria reduced the within-device variation of LB. Future work is needed to validate a suitable LB criterion against a gold standard measure (e.g., visual or video observations) for IceQube and IceTag devices in grazing dairy cows.

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