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Detecting play behaviour in weaned dairy calves using accelerometer data

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Abstract

This research paper describes a validation study evaluating the ability of IceTag accelerometers (Peacock Technology, UK) to detect play behaviour in weaned dairy calves. Play behaviour is commonly observed in young animals and is regarded as an indicator of positive welfare states. Eight Holstein Friesian calves aged three to five months old were monitored using leg-mounted accelerometers for 48 h. Data generated by accelerometers to quantify calf activity included step count, lying times and a proprietary measure of overall activity termed 'motion index' (MI). Calf behaviour was filmed continuously over the same 48-h period using closed circuit television cameras and analysed using one-zero sampling to identify the presence (1) or absence (0) of play within each 15-min time period. A positive correlation between MI and visually recorded play was found. Visual observations were compared with accelerometer-generated data and analysed using 2×2 contingency tables and classification and regression tree analysis. A MI value of ≥69 was established as the optimum threshold to detect play behaviour (sensitivity = 94.4%; specificity = 93.6%; balanced accuracy = 94.0%). The results of this study suggest that accelerometer-generated MI data have the potential to detect play behaviour in weaned dairy calves in a more time efficient manner than traditional visual observations.

Animal welfare, particularly that of calves, is a topic of growing discussion within the dairy sector and in wider society (von Keyserlingk and Weary, 2017). It is increasingly recognised that the measurement of animal welfare must not focus solely on the elimination of negative experiences and instead should be moving towards the identification and promotion of positive experiences (Lawrence *et al.*, 2019). Behavioural assessment is becoming more widely used as a method of measuring positive animal welfare (Mattiello *et al.*, 2019) and of growing interest is play behaviour, which is a spontaneous and short duration behaviour commonly observed in young animals (Burghardt, 2012). Play behaviour is not required for survival and is exhibited by animals when they feel free from stress and immediate threats to wellbeing (Held and Špinka, 2011). Play may be adversely affected by negative experiences and, accordingly, is considered to be an indicator of positive welfare (Held and Špinka, 2011; Ahloy-Dallaire *et al.*, 2018).

The study of animal behaviour has traditionally relied on manual observation or video recording to capture the undisturbed behaviour of animals in their 'home' environment (Haskell and Langford, 2023). These observational methods of behavioural assessment can be labour intensive and are often not practical for studies of long duration, or for on-farm assessment (Bateson and Martin, 2021). Precision livestock farming (PLF) is a concept that uses technology to monitor farmed animals and their environment in real-time (Beaver and Rutter, 2023), and recent PLF developments in wearable sensors for animals have provided researchers with a variety of tools that can aid in the monitoring of calf health and behaviour (Brown *et al.*, 2013; Costa *et al.*, 2021). Tri-axial accelerometer devices, which measure three-dimensional changes in body velocity over time, have the ability to record fine scale animal movements and posture changes and are increasingly being used to monitor the behaviour of livestock (Brown *et al.*, 2013; Costa *et al.*, 2021). Accelerometers have been reported to measure a variety of daily behaviours (such as lying and rumination times) in dairy calves of ages ranging from three weeks to two months old (Trénel *et al.*, 2009; Bonk *et al.*, 2013; Hill *et al.*, 2017; Roland *et al.*, 2018). The change in pattern of behaviours detected by accelerometers has been shown to aid in the early detection of disease including neonatal diarrhoea (Goharshahi *et al.*, 2021) and bovine respiratory disease (Gardaloud *et al.*, 2022).

Accelerometer technologies also have potential for use in welfare assessment as they have the capability to detect behaviours, such as play, that reflect positive welfare (Rushen *et al.*, 2012). Different accelerometer-based devices have been used in previous studies to identify play behaviour in dairy calves in differing experimental circumstances (Rushen and de Passillé, 2012; Luu *et al*., 2013; Gladden *et al*., 2020; Größbacher *et al*., 2020). Using tests in experimental arenas, studies have shown a strong correlation between summed acceleration calculated by leg mounted accelerometers and duration of locomotor play events such as running, in pre- and post-weaned calves (Rushen and de Passillé, 2012; Luu *et al*., 2013). Similarly, Größbacher *et al*. (2020) manipulated accelerometer-generated data to identify play behaviours in four and eight week old calves in their home pen. Recent work by (Gladden *et al*., 2020) validated the leg-mounted IceTag accelerometer (Peacock Technology Ltd, UK) to measure play behaviour in neonatal dairy calves (up to 48 h old) in their home pen. Importantly, this work analysed direct outputs generated by the IceTag, eliminating the need for additional processing of raw accelerometer data as was required in previous studies. Moreover, this study established a threshold to identify play based on a readily available output of the IceTag termed 'motion index (MI)', which calculates overall animal activity based on the force and duration of movement. While previous studies have shown that accelerometer data can be used to correctly identify play behaviour in dairy calves, limitations including overestimation of the number of play events and inability to record the duration and detailed nature of play have been consistently reported (Trénel *et al*., 2009; Gladden *et al*., 2020; Größbacher *et al*., 2020).

Despite there being a growing body of literature using accelerometer technology to measure calf behaviour, only a few studies have focused on measuring the behaviour of healthy, older calves in a typical commercial dairy context during the post-weaning period (Hänninen *et al*., 2005; Rushen and de Passillé, 2012). Lying and activity times have been reported for pre-weaned dairy calves (Wormsbecher *et al*., 2017; Gladden *et al*., 2019; Duthie *et al*., 2021) but not for weaned calves. The acceleration force and duration of movement in older calves is different to their younger counterparts (Rushen and de Passillé, 2012). Therefore, we hypothesised that accelerometer data thresholds established to detect play in young (pre-weaned) calves will not be appropriate for older (post-weaning) calves. The primary objective of this study was to assess the ability of IceTag accelerometers to detect play behaviour in three to five month old dairy calves, with a particular focus on MI. A secondary objective of this study was to establish, using IceTag accelerometers, a daily time budget for weaned dairy calves aged between three to five months old.

Materials and methods

Study population

Ethical approval for the study was obtained from the University of Glasgow School of Veterinary Medicine Research Ethics Committee (ref EA05/22). Eight weaned, female Holstein-Friesian dairy calves aged three to five months old (mean 118 d, SD ± 16 d) were recruited from a 50-cow dairy herd in central Scotland. Calves were housed in individual straw bedded pens from birth until weaning at eight weeks old, following which they were moved to group housing. During the study, calves were housed in a straw-bedded group pen measuring 7.3 × 13.6 m in groups of ten. Calves were fed concentrate pellets once daily and had *ad libitum* access to straw and water. Data were collected over a three-week period from February to March 2022.

Accelerometer device overview

IceTags (Peacock Technology Ltd, UK) are small (66 × 55 × 27 mm), lightweight (117 g) devices previously validated for behavioural monitoring in adult cattle and calves (Trénel *et al*., 2009; Nielsen *et al*., 2010; Ungar *et al*., 2018; Gladden *et al*., 2020). The IceTag is a tri-axial accelerometer with a high data recording frequency rate of 16 Hz (16 sample points recorded every second); data are collated to generate specified output resolutions that are dictated by the IceTag software (1 s, 1 min, 15 min, 1 h, 2 h, 1 d and 1 week). Acceleration forces occurring during animal movement are measured in three dimensions and collated by the device to generate outputs reflective of animal activity such as standing time, lying time, step count and number of lying bouts. Additionally, a proprietary metric termed 'motion index' (MI) is generated by the IceTag, by calculating the average vector sum of acceleration in three dimensions (the MI value is equivalent to the gravitational acceleration applied to the IceTag device × 10 (C. Malcolm, IceRobotics, personal communication)). Motion index combines the duration of animal movement and forces applied to the accelerometer during movement and, therefore, can be viewed as an indicator of overall animal activity (Gladden *et al*., 2020). Using this type of accelerometer, a strong positive correlation between MI and play behaviour ($R = 0.922$, $P < 0.001$) has previously been reported in newborn calves (Gladden *et al*., 2020).

Accelerometer data collection

A single IceTag was attached to one hindlimb of each calf using a methodology similar to that described by Gladden *et al*. (2020) and demonstrated in online Supplementary Fig. S1. Briefly, the IceTag was cushioned inside a small fabric sock and attached to the lateral aspect of one hindlimb of the calf, proximal to the metatarso-phalangeal joint, using cohesive bandage (Wrapz®, Millpledge Veterinary, UK). The bandage was secured at the proximal and distal aspects using a layer of elastic bandage (Tensoplast®, BSN Medical, UK). IceTags were attached to each calf for a maximum of 3 d, including a minimum 12-h period of adjustment to the device placement prior to commencing the 48-h data collection period. To provide a daily time budget for each calf, daily lying times and individual lying bout data were extracted from the IceTag and analysed over a 24-h time period from 08:00 on day 1 of the study until 08:00 the following day. To capture a representative sample of behaviour amongst the group of calves, data collection periods were staggered across the calf group and were performed over four recording periods, where a new pair of calves was enrolled at each session. IceTags were attached to only two calves at any one time, with all other calves in the pen acting as companion animals. IceTag generated data were downloaded at the end of each recording period using an IceReader device (Peacock Technology Ltd, UK) in combination with IceManager software (Peacock Technology Ltd, UK). Calf activity data were summarised in 15-min sampling intervals and exported as CSV-format files for further analysis. An output of 15-min sampling intervals was selected based on the available preset IceTag output resolutions and previous work which has demonstrated that MI output at this resolution could predict the presence or absence of play behaviour in neonatal dairy calves (Gladden *et al*., 2020).

Behavioural analysis

Calf behaviour was continuously recorded over the three-week study period using two closed circuit television cameras (CCTV: Sony CCD, Vari-focal, 700 TV L, Sony, Japan) fixed to the back

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wall of the calf shed at a height of 2.8 m, chosen to allow maximum visibility whilst not obstructing farm machinery. The cameras provided a mostly unobstructed view of the pen aside from two blind spots directly underneath each camera, as shown in Supplementary Fig. S2. Video footage was stored on digital video recorders (Guardian II + DVR 8 Channel, Digital Direct Security, UK) and extracted at the end of the study period. To allow identification from video recordings, calves were marked along their back with a unique colour of agricultural spray which was recorded alongside the calf ID and IceTag serial number.

Extracts of video recordings were time matched to the 48-h IceTag data collection period and analysed individually for each calf. Play behaviour was measured using one-zero sampling (Altmann, 1974) at 15-min intervals corresponding with the IceTag output. Play was identified based on an ethogram of calf locomotor play behaviour (Table 1) based on previous work by Jensen *et al.* (1998). The ethogram was modified to include only locomotor play behaviours as these behaviours typically include leg movement, recorded here due to the positioning of the IceTag on the hindlimb. If any behaviour identified as play, regardless of count or duration, occurred during the given 15-min interval, this entire time period was recorded as 'Play (1)'. If no play was observed during the selected 15-min interval, this entire time period was recorded as 'No Play (0)'. Time periods where the calf was not observed due to positioning out with the camera range were recorded as 'Not Visible'.

Complete IceTag and video datasets were available for all eight calves, with 192 15-min intervals per calf and a combined total of 1536 15-min intervals available for the initial analysis. However, due to camera positioning, calves were not visible in 4.8% (73/1536) of the 15-min intervals, and these time periods were excluded from any visual analysis of calf behaviour. Accordingly, IceTag data analysis was based on a cumulative total of 1536 sample intervals, while correlation of video derived calf behaviour data with MI data and the calculation of the optimal MI threshold to determine play was based on a cumulative total of 1463 sample intervals.

Table 1. Ethogram of calf locomotor play behaviour (adapted from (Jensen *et al.*, 1998))

Locomotor play event	Description
Buck (low)	The calf raises both hindlimbs simultaneously with the hooves remaining below the tarsal joints.
Buck (high)	The calf raises both hindlimbs simultaneously with the hooves raised to at or above the tarsal joints.
Buck-kick	The calf raises both hindlimbs simultaneously with the hooves raised to at or above the tarsal joints. One or both hindlimbs are kicked out in a caudal or lateral direction.
Gallop	The calf moves with a fast four-beat gait that includes a period of suspension in air.
Jump	The calf lifts both forelimbs from the ground and elevates the front of the body to move upwards. The hindlimbs may also be lifted from the ground during the last phase of movement.
Leap	The calf lifts both forelimbs from the ground and stretches the front of the body to move forward. The hindlimbs may also be lifted from the ground during the last phase of movement.
Turn	The calf lifts both forelimbs from the ground and elevates then turns the front of the body to one side to move sideways.

Statistical analysis

Corresponding intervals of IceTag MI data and video behavioural analysis were combined and summarised in Microsoft Excel (Version 2308, Microsoft Corporation, USA) then exported for analysis in Minitab (Version 20, Minitab LLC, USA).

Descriptive statistics were calculated separately in Minitab for IceTag and visual observations. Lying times and lying bouts of individual calves were assessed using IceTag generated data, which has previously been validated by Trénel *et al.* (2009) to accurately estimate standing and lying activities in group housed dairy calves. To indicate whether more detailed analysis was appropriate, the Mann–Whitey U test was used to determine whether MI was associated with the presence or absence of play. Statistical significance was considered at a P-value of <0.05. Motion index values and one-zero sampling results were formatted in 2×2 contingency tables to determine the sensitivity (Se), specificity (Sp) and balanced accuracy of selected MI threshold values to detect play behaviour. These values were calculated for each MI threshold point using the following formulae:

$$\text{Se} = (\text{true positive play events})/(\text{true positive play events} + \text{false negative play events})$$

$$\text{Sp} = (\text{true negative play events})/(\text{true negative play events} + \text{false positive play events})$$

$$\text{Balanced accuracy} = (\text{Se} + \text{Sp})/2$$

Different MI threshold values (a range of 25 to 300) were investigated with this method to determine the value which provided optimal sensitivity, specificity and balanced accuracy. The MI threshold value which would best indicate play was selected based on optimal balanced accuracy, as this figure represents the best balance between specificity and sensitivity. The optimal MI threshold to detect play behaviour was confirmed using classification and regression tree (CART) analysis performed using the Gini node splitting method. Data was subdivided into training and test datasets by the CART model using 10-fold cross validation. Performance of the model determined MI threshold in identifying play was summarised using a confusion matrix and receiver operating characteristic (ROC) curve.

Results

Description of behavioural analysis and IceTag activity data

Lying times and lying bout data output by the IceTags were assessed for all calves for a 24-h period (Table 2). Mean (SD) daily lying time was 16.1 ± 0.71 h/d. Calves spent an average 67.1% of their day lying compared to an average 32.9% of time standing or engaged in activity. The median (SD) number of lying bouts per day was 42 ± 13. The mean (SD) length of lying bout was 21.9 ± 5.7 min.

Based on visual one-zero sampling, across all test calves, play was recorded in 13.5% (197/1463) of the visible 15-min intervals; no play was recorded in 86.5% (1266/1463). For individual animals, the percentage of visible 15-min intervals in which play

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Table 2. Summary statistics (range, mean and median) of visual one-zero behavioural analysis and IceTag activity data for all test calves ($n = 8$)

Variable	Minimum	Maximum	Mean	Median
Visual Observations[a]				
Play (% of visible intervals)	5.3	21.0	13.5	
No play (% of visible intervals)	79.0	94.7	86.5	
IceTag Motion Index Output[b]				
Motion index overall	0	2343		6
Motion index during play	25	2343		130
Motion index during no play	0	280		1
Motion index during not visible	0	119		6
IceTag Lying Activity Output[c]				
Lying time (hours)	15.4	17.5	16.1	
Lying (%)	64.1	72.9	67.1	
Lying bouts	32	74		42
Lying bout length (min)	12.9	29.5	21.9	

[a]Behavioural observations based on one-zero sampling of calf activity while visible over 1463 15-min intervals.
[b]Motion index values based on IceTag output of 1536 15-min intervals.
cDaily calf lying activity based on IceTag output over a 24-h period.

was recorded ranged from 5.3% (9/169) to 21.0% (39/186: Table 2). Motion index values varied depending on the calves' activity state, as indicated by one-zero sampling (Table 2). Overall, regardless of activity state, MI ranged from 0 to 2343 (median 6). In intervals where one-zero sampling indicated calves to be engaged in play, MI ranged from 25 to 2343 and in intervals where no play was recorded, MI ranged from 0 to 280. A significant difference was found between the median MI for intervals with play recorded (median = 130) compared to intervals where no play was recorded (median = 1) ($P < 0.001$).

Calculation of optimal MI threshold to determine play

Results of manual threshold determination for a selection of MI cut off points are presented in Table 3. Maximum sensitivity (Se = 100%) was associated with a MI threshold of ≥ 25. However, specificity and balanced accuracy were low at 28.8 and 64.4% respectively. Maximum specificity (Sp = 100%) was associated with a MI threshold of ≥ 281, but at this threshold sensitivity was poor at 14.2% and balanced accuracy was moderate at 57.1%. A threshold of ≥ 69 provided the most balanced overall performance, with 94.4% sensitivity, 93.6% specificity and 94.0% balanced accuracy. The count and percentage of true positive, true negative, false positive and false negative play events at this optimal MI threshold are presented in Table 4. Classification and regression tree analysis indicated that the optimum MI threshold for determining play was MI ≥ 68.5, with excellent overall performance in the model's training (Se = 94.4%; Se = 93.6%) and test (Se = 93.9%; Sp = 91.7%) datasets. The area under the ROC curve for the training and test datasets were 0.94 (95% CI 0.48–1.0) and 0.93 (95% CI 0.91–0.95) respectively (Fig. 1).

Table 3. Results of manual sensitivity, specificity and balanced accuracy calculations for various MI threshold values

Motion Index Threshold	Sensitivity (%)	Specificity (%)	Balanced Accuracy (%)
≥ 25	100	28.75	64.38
≥ 60	95.43	91.00	93.21
≥ 65	94.92	92.58	93.75
≥ 66	94.92	92.65	93.79
≥ 67	94.92	92.73	93.83
≥ 68	94.42	93.13	93.77
≥ 69	94.42	93.60	94.01
≥ 70	93.40	93.92	93.66
≥ 80	89.34	96.37	92.85
≥ 281	14.21	100	57.11

Discussion

Previous studies have demonstrated the ability of leg-mounted accelerometer devices to identify play behaviour in dairy calves of different ages (Rushen and de Passillé, 2012; Luu *et al.*, 2013; Gladden *et al.*, 2020; Größbacher *et al.*, 2020). Similarly, our study has shown that IceTag accelerometer generated data can

Table 4. Contingency table demonstrating the count and percentage of true positive, true negative, false positive and false negative play events at a MI threshold of ≥ 69

	Play (1)	No Play (0)	Total
MI < 69			
Count (%)	11 (0.75%)	1185 (81.00%)	1196 (81.75%)
MI ≥ 69			
Count (%)	186 (12.71%)	81 (5.54%)	267 (18.25%)
Total			
Count (%)	197 (13.47%)	1266 (86.53%)	1463 (100.00%)

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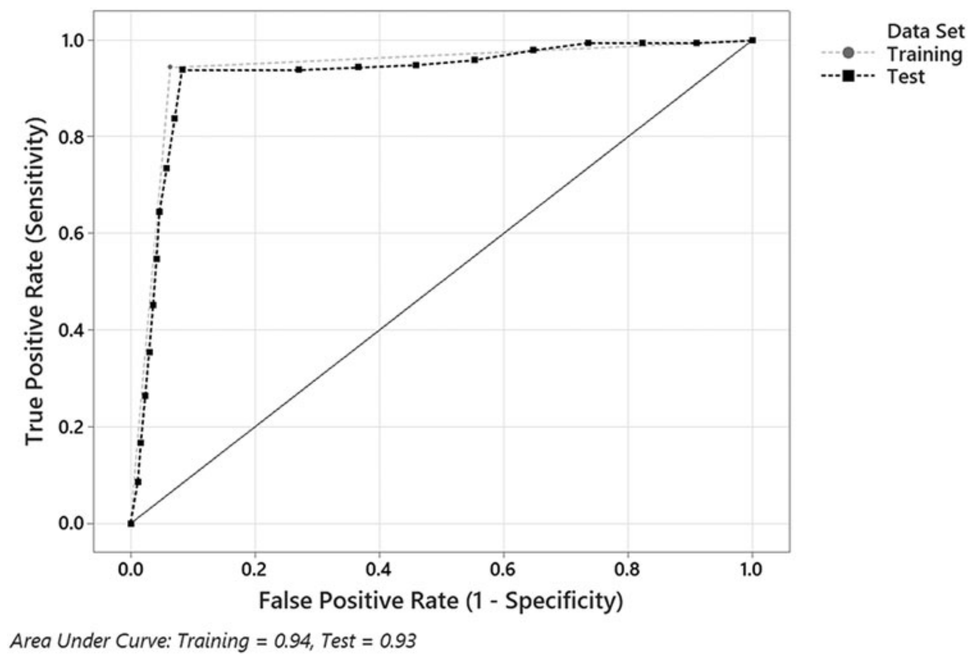

Figure 1. Receiver operating characteristic curve demonstrating the sensitivity and specificity of MI threshold ≥ 68.5 to determine play behaviour. The area under the curve for the training dataset (grey dashed line) was 0.94 and for the test dataset (black dashed line) was 0.93.

identify play behaviour in weaned dairy calves (aged three to five months old) in their home pen. The results of our study suggest that MI values generated in 15-min sample intervals can reliably detect play behaviour at a threshold of 69. By contrast, in a similar study Gladden *et al.* (2020) found play behaviour in younger calves was identified using an MI threshold of 24.5, which was lower than our findings. It should be considered that this finding was expected, given that MI is a measure of overall animal activity and weaned calves are known to move with greater acceleration than younger calves (Rushen and de Passillé, 2012), and supports our hypothesis that accelerometer generated data thresholds for detecting play differ with calf age.

Previous work investigating the use of accelerometers to monitor calf behaviour has highlighted the limitations of this technology in being able to accurately describe the nature of specific behaviours (Trénel *et al.*, 2009; Gladden *et al.*, 2020; Größbacher *et al.*, 2020). Similarly, in this study the technique used to identify play behaviour is comparable to one-zero sampling, whereby within any given 15-min interval a score of 'Play (1)' or 'No play (0)' was assigned but the exact duration or number of play events of individual calves could not be determined. Despite defining a threshold with high sensitivity and specificity (94.4 and 93.6%, respectively) to detect play behaviour, the use of 15-min sampling intervals further limits accurate assessment of play as multiple play events could occur within this period but would not be counted individually. Therefore, future work to determine the performance of lower IceTag resolutions (e.g. 1-min sampling intervals) may be warranted to provide a more accurate estimation of play behaviour in weaned dairy calves. Overall, the methods described in this study are beneficial for providing a proxy measurement of play events within a 15-min sampling period, however, if a more detailed description of the nature of play is desired then shorter sampling intervals or continuous observational methods of behavioural assessment may be preferred (Haskell and Langford, 2023).

It is known that young dairy calves spend a large portion of their daily time budget engaged in lying behaviours (Whalin *et al.*, 2021), but no studies have examined the daily time budget of dairy calves of the age studied here. Newborn calves housed in groups are reported to spend over 80% of their daily time budget lying (Gladden *et al.*, 2019), whereas slightly older animals (three to four weeks old) have been reported to spend approximately 70% of their daily time budget lying with lying times of between 16.7 and 16.9 h per day reported (Wormsbecher *et al.*, 2017; Duthie *et al.*, 2021). Similarly, calves in the present study were found to be engaged in lying behaviours for 67% of their day (16.1 h/d). This finding is consistent with previous research which describes a decrease in resting behaviour with increasing age in calves studied up to five months old (Hänninen *et al.*, 2005). Understanding the typical lying and activity patterns of calves is important, as deviations from normal lying times may be associated with stressful events such as onset of disease (Duthie *et al.*, 2021; Goharshahi *et al.*, 2021; Gardaloud *et al.*, 2022), heat stress (Kovács *et al.*, 2018) and introduction to social grouping (Horvath and Miller-Cushon, 2018).

While weaned calves were found to spend a similar amount of time per day lying to the times reported by other authors for younger calves, the pattern of lying behaviour was not similar. The calves in our study engaged in a higher number of shorter duration lying bouts than calves in previous studies, which report less frequent (mean 19.6 bouts/d), longer duration (mean 56 min/bout) lying periods in younger calves housed and managed under similar conditions (Duthie *et al.*, 2021). Increased frequency of lying has been related to discomfort or disrupted rest patterns in both calves and adult cattle (Vasseur *et al.*, 2012; Kovács *et al.*, 2018). The positioning of the calf shed in this study meant that calves had frequent visual contact with people and farm machinery, and it is possible that the lying patterns observed here are reflective of interrupted rest due to a busy environment rather than an impact of age or housing. A variation in individual

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lying bout frequency and duration was observed between calves in this study. This is believed to be a normal behavioural variation as similar differences in daily lying periods have been reported in adult cattle, with animal level factors such as parity or stage of lactation and farm level factors such as bedding type or overstocking reported to influence both overall lying times and the frequency and length of lying bouts (Tucker *et al*., 2021).

Given the complexity of a calf's interaction with their environment (Whalin *et al*., 2021), a limitation of this study is that the results may not be transferable to calves of different ages reared in different conditions, as alternative environments may alter the dynamics of how calves play. Furthermore, the amount of time calves engage in play will be influenced by housing and management related factors such as space allowance, housing group size and feeding or weaning management (Jensen *et al*., 1998; Krachun *et al*., 2010). Similar to the study reported here, existing studies typically analyse behaviours of dairy calves reared in a commercial, indoor housing setting. Further work is warranted to compare play behaviour of weaned dairy calves reared under different conditions.

While this study offers a practical approach to measuring play behaviour in weaned dairy calves, the devices and methodology described are currently limited to a research-based setting. PLF technologies have been developing in the dairy industry over the past four decades (Beaver and Rutter, 2023) and now many accelerometer devices are commercially available for measuring calf health and behaviour in an on-farm setting (Costa *et al*., 2021). These devices may measure at different sampling frequencies or be worn by the calf on areas other than the leg (Costa *et al*., 2021); therefore, the data output may differ to that reported here. In addition, these devices may have the ability to capture other forms of play behaviour not measured in this study such as social play, which typically involves head and neck movement (Held and Špinka, 2011). Given that there is a known relationship between play behaviour and positive welfare states (Held and Špinka, 2011; Ahloy-Dallaire *et al*., 2018), validation of such devices to measure play offers potential for real-time, on farm assessment of calf welfare. Further research investigating the ability of commercially available calf accelerometer technology to measure play behaviour is merited.

In conclusion, this study has shown that IceTag accelerometers can reliably detect play behaviour in weaned dairy calves and contributes to the growing body of literature highlighting the value of sensor technology for measuring calf behaviour. Developing technology to detect play behaviour is particularly important, given that play is considered to be an indicator of positive welfare but has historically been difficult to reliably measure given it's short-lived and spontaneous nature. Future work validating commercially available accelerometer devices in calves under different management conditions is warranted to facilitate the extension of this technology into a commercial environment for use as a practical farm-based welfare assessment tool.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/S0022029924000542

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References

Ahloy-Dallaire J, Espinosa J and Mason G (2018) Play and optimal welfare: does play indicate the presence of positive affective states? *Behavioural Processes* **156**, 3–15.

Altmann J (1974) Observational study of behaviour: sampling methods. *Behaviour* **49**, 227–267.

Bateson M and Martin P (2021) Recording methods. In Bateson M and Martin P (eds), *Measuring Behaviour: An Introductory Guide*, 4th Edn. Cambridge: Cambridge University Press, pp. 94–109.

Beaver A and Rutter SM (2023) Precision livestock farming technologies for dairy and beef production. In Haskell M (ed.), *Cattle Welfare in Dairy and Beef Systems*, 1st Edn. Cham, Switzerland: Springer, pp. 297–321.

Bonk S, Burfeind O, Suthar *and* Heuwieser W (2013) Technical note: evaluation of data loggers for measuring lying behavior in dairy calves. *Journal of Dairy Science* **96**, 3265–3271.

Brown D, Kays R, Wikelski M, Wilson R and Klimley AP (2013) Observing the unwatchable through acceleration logging of animal behavior. *Animal Biotelemetry* **1**, 1–16.

Burghardt GM (2012) Defining and recognizing play. In Nathan P and Pellegrini AD (eds), *The Oxford Handbook of the Development of Play*, Online Edn. New York: Oxford University Press, pp. 9–18.

Costa JHC, Cantor MC and Neave HW (2021) Symposium review: precision technologies for dairy calves and management applications. *Journal of Dairy Science* **104**, 1203–1219.

Duthie CA, Bowen JM, Bell DJ, Miller GA, Mason C and Haskell MJ (2021) Feeding behaviour and activity as early indicators of disease in pre-weaned dairy calves. *Animal: An International Journal of Animal Bioscience* **15**, 100150.

Gardaloud NR, Guse C, Lidauer L, Steininger A, Kickinger F, Öhlschuster M, Auer W, Iwersen M, Drillich M and Klein-Jöbstl D (2022) Early detection of respiratory diseases in calves by use of an ear-attached accelerometer. *Animals* **12**, 1093.

Gladden N, Ellis K, Martin J, Viora L and McKeegan D (2019) A single dose of ketoprofen in the immediate postpartum period has the potential to improve dairy calf welfare in the first 48 h of life. *Applied Animal Behaviour Science* **212**, 19–29.

Gladden N, Cuthbert E, Ellis K and McKeegan D (2020) Use of a tri-axial accelerometer can reliably detect play behaviour in newborn calves. *Animals* **10**, 1137.

Goharshahi M, Azizzadeh M, Lidauer L, Steininger A, Kickinger F, Öhlschuster M, Auer W, Klein-Jöbstl D, Drillich M and Iwersen M (2021) Monitoring selected behaviors of calves by use of an ear-attached accelerometer for detecting early indicators of diarrhea. *Journal of Dairy Science* **104**, 6013–6019.

Größbacher V, Bučková K, Lawrence AB, Špinka M and Winckler C (2020) Discriminating spontaneous locomotor play of dairy calves using accelerometers. *Journal of Dairy Science* **103**, 1866–1873.

Hänninen L, De Passillé AM and Rushen J (2005) The effect of flooring type and social grouping on the rest and growth of dairy calves. *Applied Animal Behaviour Science* **91**, 193–204.

Haskell MJ and Langford FM (2023) Using behaviour to understand and assess welfare in cattle. In Haskell M (ed.), *Cattle Welfare in Dairy and Beef Systems*, 1st Edn. Cham, Switzerland: Springer, pp. 15–53.

Held SDE and Špinka M (2011) Animal play and animal welfare. *Animal Behaviour* **81**, 891–899.

Hill TM, Suarez-Mena FX, Hu W, Dennis TS, Schlotterbeck RL, Timms LL and Hulbert LE (2017) Technical note: evaluation of an ear-attached movement sensor to record rumination, eating, and activity behaviors in 1-month-old calves. *Professional Animal Scientist* **33**, 743–747.

Horvath KC and Miller-Cushon EK (2018) Characterizing social behavior, activity, and associations between cognition and behavior upon social grouping of weaned dairy calves. *Journal of Dairy Science* **101**, 7287–7296.

Jensen MB, Vestergaard KS and Krohn CC (1998) Play behaviour in dairy calves kept in pens: the effect of social contact and space allowance. *Applied Animal Behaviour Science* **56**, 97–108.

Kovács L, Kézér FL, Bakony M, Jurkovich V and Szenci O (2018) Lying down frequency as a discomfort index in heat stressed Holstein bull calves. *Scientific Reports* **8**, 15065.

Krachun C, Rushen J and de Passillé AM (2010) Play behaviour in dairy calves is reduced by weaning and by a low energy intake. *Applied Animal Behaviour Science* **122**, 71–76.

Lawrence AB, Vigors B and Sandøe P (2019) What is so positive about positive animal welfare? – A critical review of the literature. *Animals* **9**, 783.

Luu J, Johnsen JF, de Passillé AM and Rushen J (2013) Which measures of acceleration best estimate the duration of locomotor play by dairy calves? *Applied Animal Behaviour Science* **148**, 21–27.

Mattiello S, Battini M, De Rosa G, Napolitano F and Dwyer C (2019) How can we assess positive welfare in ruminants? *Animals* **9**, 758.

Nielsen LR, Pedersen AR, Herskin MS and Munksgaard L (2010) Quantifying walking and standing behaviour of dairy cows using a moving average based on output from an accelerometer. *Applied Animal Behaviour Science* **127**, 12–19.

Roland L, Lidauer L, Sattlecker G, Kickinger F, Auer W, Sturm V, Efrosinin D, Drillich M and Iwersen M (2018) Monitoring drinking behavior in bucket-fed dairy calves using an ear-attached tri-axial accelerometer: a pilot study. *Computers and Electronics in Agriculture* **145**, 298–301.

Rushen J and de Passillé AM (2012) Automated measurement of acceleration can detect effects of age, dehorning and weaning on locomotor play of calves. *Applied Animal Behaviour Science* **139**, 169–174.

Rushen J, Chapinal N and de Passillé AM (2012) Automated monitoring of behavioural-based animal welfare indicators. *Animal Welfare* **21**, 339–350.

Trénel P, Jensen MB, Decker EL and Skjøth F (2009) Technical note: quantifying and characterizing behavior in dairy calves using the IceTag automatic recording device. *Journal of Dairy Science* **92**, 3397–3401.

Tucker CB, Jensen MB, de Passillé AM, Hänninen L and Rushen J (2021) Invited review: lying time and the welfare of dairy cows. *Journal of Dairy Science* **104**, 20–46.

Ungar ED, Nevo Y, Baram H and Arieli A (2018) Evaluation of the IceTag leg sensor and its derivative models to predict behaviour, using beef cattle on rangeland. *Journal of Neuroscience Methods* **300**, 127–137.

Vasseur E, Rushen J, Haley DB and de Passillé AM (2012) Sampling cows to assess lying time for on-farm animal welfare assessment. *Journal of Dairy Science* **95**, 4968–4977.

von Keyserlingk MAG and Weary DM (2017) A 100-year review: animal welfare in the Journal of Dairy Science – the first 100 years. *Journal of Dairy Science* **100**, 10432–10444.

Whalin L, Weary DM and von Keyserlingk MAG (2021) Understanding behavioural development of calves in natural settings to inform calf management. *Animals* **11**, 2446.

Wormsbecher L, Bergeron R, Haley D, de Passillé AM, Rushen J and Vasseur E (2017) A method of outdoor housing dairy calves in pairs using individual calf hutches. *Journal of Dairy Science* **100**, 7493–7506.

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