Ear-attached accelerometer as an on-farm device to predict the onset of calving in dairy cows

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Abstract. *The objective of this study on an ear-attached accelerometer in dairy cows was (1) to determine activity, rumination and lying time of the dams prior to calving, and include group level of measured variables (2) use the data to develop an algorithm to predict calving and (3) to test the performance of this algorithm. Video observations (24h/d) were used as reference for these events. Four weeks before expected calving, an ear-tag integrated tri-axial accelerometer (SMARTBOW system) was attached to the dam's ear. A total of 894 data sets were analyzed from 2 weeks before estimated calving until the expulsion of the calf. The data set was divided into training, validation and test data sets. Input variables based on accelerometer data were used to develop an algorithm for calving prediction and included rumination time, activity level and lying time of individual animals and on group level. To model the upcoming calving on the basis of the input variables, Transfer Function models were used. The performance of the algorithm to predict calving in the time periods of 72, 48, 24, 12, 6, 3 and 1 h before expulsion of the calf was determined. Greatest accuracy (94%) was achieved at -12 h and maintained on this level until the expulsion of the calf. Greatest sensitivity was achieved at -1 h (54%), lowest sensitivity was found at -72 h (19%). Our findings indicate that accelerometer-based prediction of parturition with the SMARTBOW system using the described input variables is eligible to support calving management in dairy cows. Further studies should test and improve the algorithm under different farming and management systems.*

Keywords. *Dairy cow, monitoring of calving, accelerometer, test performance.*

Introduction

Reproductive performance of cows is essential for the economic outcome of dairy farms. The basis for a good performance is set at parturition. Dystocia and periparturient diseases can have detrimental effects for the dam, the calf and finally for the economic profitability of the farm. Stillbirth and perinatal mortality are a problem on many dairy farms worldwide (Mee et al. 2013). Dystocia is associated with stillbirth and death of the calves up to 30 days of age (Lombard et al. 2007). Surviving calves are at higher risk for suffering from higher morbidity, mortality and poor welfare (Barrier et al. 2013). In dams, dystocia is associated with increasing incidence of postpartum diseases, decrease in milk production and reproductive performance, finally resulting in increased culling rates (Kim et al. 2016). Therefore, a good calving management is important to prevent peripartal mortality (Mee 2004). It has been discussed whether early intervention during calving is beneficial or even detrimental. Recent studies have shown that early assistance at calving as a routine has no negative impact on calves' stillbirth risk, vigor at birth, transfer of passive immunity, whereas late intervention resulted in a higher chance of stillbirth (Villettaz Robichaud et al. 2017a; Villettaz Robichaud et al. 2017b).

Prior to parturition, many behavioral changes can be observed in cows, e.g. separation from the herd (Proudfoot et al. 2014), increased activity (Jensen 2012), increased frequencies of lying and tail raising (Miedema et al. 2011), decreased feeding and drinking activity (Jensen 2012) and rumination time (Schirmann et al. 2013; Büchel and Sundrum 2014; Clark et al. 2015). Continuous monitoring systems may detect some of these changes in the dam's behavior and can be used to predict the onset of parturition. Different systems are available and include inclinometers and accelerometers perceiving tail raising and activity, abdominal belts detecting uterine contractions, vaginal probes measuring vaginal temperature, and devices detecting the expulsion of the calf (reviewed by Saint-Dizier and Chastant-Maillard 2015). The combination of, e.g. neck activity and rumination data (Borchers et al. 2017), rumination, activity, reticuloruminal pH and temperature (Kovacs et al. 2017) by continuous sensor monitoring can improve the accuracy of calving prediction.

The SMARTBOW Eartag (Smartbow GmbH, Weibern, Austria) is a monitoring system that is based on an accelerometer that measures the acceleration in three axes (x-, y- and z-axis) caused by the head and/or ear movements of the cow. The ear-attached accelerometer collects data in real-time and offers commercially available functionalities for heat detection, rumination monitoring (Reiter et al. 2018) and the localization of cows. The modification as a tail-attached accelerometer to predict calving was investigated in a pilot study by the authors of this manuscript and provided valuable information for the present study (Krieger et al. 2017).

The objective of this study was (1) to determine activity, rumination and lying time of the dams prior to calving, and include group level of measured variables (2) use the data to develop an algorithm to predict calving and (3) to test the performance of this algorithm.

Material and methods

Animals and housing

The study was conducted between May 2016 and January 2017 on a large-scale dairy farm in Slovakia, housing approximately 2,700 Holstein Frisian cows and additional youngstock. The average energy corrected milk yield was 9,260 kg per cow and year. Dry cows were housed during the close-up period and in the group calving pen on deep straw bedding. Lactating cows were kept in groups of approximately 200 animals in free stall barns with concrete floors, and high-bed cubicles covered with rubber mattresses and dried slurry separator material. All pens were equipped with headlocks and feed rails. Heifers were kept on another farm site and, thus not included in this study.

In the close-up group, cows were fed a TMR twice daily and had free access to water. The ration consisted of straw, corn silage, sorghum, alfalfa silage, wet distiller's grain with solubles) hay, and a premix (rapeseed meal, minerals).

During the study period, average ambient temperature was 21.1°C from May to September (min. 5.8°C, max. 32.4°C) and 6.2°C (-10.8°C to 24.5°C) from October to January.

All animal use was approved by the institutional ethics committee of the University of Veterinary Medicine Vienna, Austria and the national authority according to § 26 of the Law for Animal Experiments, Tierversuchsgesetz 2012 – TVG 2012 (GZ 68.205/0007-II/3b/2014) as well as by the Slovakian Regional Veterinary Food Administration (Bratislava).

Management of dry cows and calving

Cows were dried off 6 weeks before expected calving, calculated from a gestation period of 280 days. Approximately 2 weeks prior to parturition, cows were moved to one of two close-up pens, with an average stocking density of 30 (pen 1) and 70 (pen 2) cows. When a dam showed signs of imminent calving, she was moved to the group calving pen. Some cows, however, were not brought to the calving pen, because of, e.g. onset of parturition was not detected in time. These cows gave birth in the close-up pens. Monitoring the dams in the close-up group, moving cows to the calving pen, supervision during parturition and the decision to assist calvings was performed by the farm staff. The calving personnel kept a 24 h calving log, containing the day and time of the expulsion of the calf, national and within herd identification numbers.

Video observation of calvings

During the study period, close-up and calving pens were equipped with 9 cameras with integrated infrared illuminators above the pens (IR Bullet Network Camera DS-2CD2632F-I(S), Hikvision, Hangzhou, China), connected with a PC and the client software (Hikvision iVMS-4200, Hikvision, Hangzhou, China) that allowed simultaneous recordings of all cameras. The video files were stored on 6 TB hard drives (WD 6 TB Purple, Western Digital, Surrey, UK) in MPEG-4 format. Additionally, we inspected the calving log on a daily basis to avoid any error with the cow identification on the video.

Videos were used as reference ('gold standard') to determine the time of expulsion of the calf. Furthermore, videos served as a time recording when cows were moved to the calving pen, for retrospective classification of calving assistance, and the condition of the newborn calf (Table 1). End of expulsion of the calf was set as primary variable. The onset of labor was not reliably detectable on the videos and was therefore not used as primary variable. For the same reason, head-lifting of the calves provided the only unmistakable sign of vitality on the videos. Animals not entirely visible during birth were excluded from the analyses.

Table 1. Score of the monitored video observation variables.

Variable	Score/Category				
	0	1	2	3	4
Moved to calving pen[1]	No	Yes			
Intervention[2] during calving	Not observed	No assistance	Partial assistance (1 person)	Moderate assistance (2 persons) or calf jack used	Veterinarian required (caesarian section, etc.)
Vitality calf[3]	Lifts head <1min	Lifts head >1<3min	Lifts head >3min	Dead	

[1]No=Cow calved in the close-up group, Yes=Cow was moved to the calving pen after showing first signs of birth
[2]Assistance was defined as pulling the calf during birth
[3]Calf is lying on the flank and lifts/shakes the head on its own the first time after the expulsion

Data collection and algorithm developement

Accelerometer

Four weeks before expected calving, we fixed the SMARTBOW Eartag sensor (size and weight of 52 x 36 x 17 mm and 34 g) to the dam's ear. Acceleration data were recorded with a frequency of 10 Hz and ranged from -2 to +2 g. Data were sent to wall mounted receivers (SMARTBOW Indoor Receiver) and forwarded to a local server (SMARTBOW Farm Server).

Sensor data

We used the acceleration data comprising the time from entering the close-up pen approximately 2 weeks before estimated day of calving until the expulsion of the calf. Data with no reliable corresponding video observation of the calving process, e.g. due to cow's position to the camera were excluded from the study. Thus, the final data set comprised 894 calving events. This set was stratified by month of calving into 11 subsets. In the next step, the data set was divided into training, validation and test data sets. Within each month, animals were randomly grouped into pairs. The first animal of the pair was assigned into the training and validation sets (n=450) to create a prediction algorithm, the second animal of the pair was allocated to the test set (n=444) for testing the final model in an unused data set. In a next step, animals in the training and validation set for each month were grouped into triplets, and 2 out of 3 animals were assigned to training set (n = 300) and 1 to validation set (n = 150). This procedure avoided a bias according to seasons, farm management, feed ration and stocking density.

Algorithm development

Input variables

Input variables rumination time, activity level and lying time of individual animals and on group level were used in order to estimate an algorithm for calving prediction. All input variables were derived from acceleration data recorded by the SMARTBOW system. Rumination time (Borchers et al. 2016; Reiter et al. 2018) and lying time were estimated with an existing algorithm developed by Smartbow. 'Activity level' was calculated as standard deviation of total acceleration from equation:

$$A_l = \sqrt{\frac{\sum_{i=1}^{600}(a_i - \bar{a})^2}{600-1}}$$

, where total acceleration was calculated according to an equation $a = \sqrt{x^2 + y^2 + z^2}$; x, y and z were vectors of acceleration of each of three accelerometer axes (Martiskainen et al. 2009). In the next step, mean of rumination and lying time was calculated on a window of 600 data points corresponding to duration of one minute. 'Activity level' was calculated as a standard deviation of total acceleration also on a window of 600 data points. Thus, one hour of data of three individual input variables was corresponding to a matrix with 60 rows and 3 columns. The purpose of averaging rumination and lying time and calculating standard deviation on a one minute window was to compress the data set and make algorithm development more efficient.

To calculate group level variables, individual variables were averaged in each minute of the study, among all animals in the close-up group at this particular minute. The purpose of adding information on group level to the model was to reduce misclassifications caused by circadian pattern, e.g. decrease of rumination time in the morning (Beauchemin et al. 1990) and procedures performed on groups of animals, e.g. a weekly footbath.

Transfer function models

To model the upcoming calving on the basis of the input variables, Transfer Function (TF) models were used. First, variables were smoothed with Integrated Random Walk (IRW) (Young, 2011) and with the value of noise-to-variance ratio (NVR) of 0.000000000007. The value of NVR was estimated with a maximum likelihood estimation method. For each input variable a separate TF model was estimated for a time window of 6 h before expulsion of the calf, because in this time period rumination and lying time as well as activity change significantly before calving (Borchers et al. 2017). The TF model type was single-input single-output (SISO; Young 2011). The Captain toolbox in Matlab 2014b (Mathworks, Natick, MA, USA) was used to estimate model variables with a refined instrumental variable approach (Young 2011). The resulting models were evaluated by the coefficient of determination R^2 (Young and Lees 1993), and an identification procedure was used to select the most appropriate model order based on the minimisation of the Young Identification Criterion (Young and Lees 1993). The smaller the variance of the model residuals in relation to the variance of the measured output, the more negative this term becomes.

In total, 1800 TF models were estimated on the input variables in the training data set (n = 300 animals). Models were validated on the validation data set (n = 150 animals) to select an optimal value of R^2 threshold which indicates imminent calving. The R^2 threshold was a mean of R^2 of the model input variables. The higher R^2, the better a certain model fitted the dynamics of the model input variables. Finally, the models' performance was tested in the testing data set (n = 444 animals).

Statistical analysis

For analyzing the measured variables, the following 5 groups were formed: all dams from the test set (ALL), cows that were moved to the calving pen before parturition (MOVED), animals that calved in the close-up group (NOT MOVED), animals with assisted calving (score ≥3) and/or insufficient calf vitality (score ≥2) (DIFF), and animals with minor or no assistance during calving (score ≤2) and/or vital calves (score ≤ 1) (NORM). Data for activity (value/h), lying time (min/h) and rumination time (min/h) were averaged for each group in 3 periods of time: in '12 d period' that covered the whole surveillance period (days -12, -11, -10, .9, -8, -7, -6, -5, -4, -3, -2, -1), values were averaged in 24 h intervals; in '72 h period' i.e. the intermediate time before calving (hours -72, -60, -48, -36, -24, -12), values were averaged in 12 h intervals; and in '24 h period' i.e. time immediately before calving, values were averaged in 2 h intervals (hours -24, -22, -20, -18, -16, -14, -12, -10, -8, -6, -4, -2).

Variables were checked for normal distribution by Kolmogorov-Smirnov test. To evaluate the change of the measured values over the course of the three time periods, Friedman's test for more than two variables was used. The Dunn-Bonferroni test was chosen as post-hoc test. To compare the groups MOVED and NOT MOVED, as well as DIFF and NORM, data was analyzed by Mann-Whitney U test for independent variables (Pahl et al. 2014). In all tests, level of significance was set as $P < 0.05$. Statistical analyses were performed with IBM SPSS Statistics for Windows, version 24 (IBM Corp., Armonk, N.Y., USA).

The performance of the developed algorithm was quantified by parameters 'accuracy', 'sensitivity' and 'specificity', defined as:

accuracy = (n of true positives + n of true negatives) / (n of true positives + n of false positives + n of false negatives + n of true negatives)

sensitivity = (n of true positives) / (n of true positives + n of false negatives)

specificity = (n of true negatives) / (n of true negatives + n of false positives)

‘True positive’ is the correct detection of an event that is also present in the reference data, ‘true negative’ is the correct detection of an event that is not present in reference data, ‘false positive’ is the incorrect detection of event which is not present in reference data, and ‘false negative’ is the incorrect detection of an event that is not present in reference data.

We used seven periods of different duration: 72 h, 48 h, 24 h, 12 h, 6 h, 3h, and 1 h to evaluate the performance of the algorithm. When a 15 min event was classified by the algorithm as positive within these periods, it was a ‘true positive’ event. If the same event was classified as negative, then it was a ‘false negative’ event. In case a 15 min event was classified as positive earlier than in defined periods, it was considered ‘false positive’. If the same event was classified as negative then it was a ‘true negative’ event.

Results

Table 2 specifies the variables of all monitored calvings and the test set in particular. If the onset of parturition was recognized by the farm staff in time, dams were moved into the calving pen on average 2 h and 8 min before the expulsion of the calf (MOVE, n=451). In particular, 65% (n=294) were moved no later than 2 h before parturition, 29% (n=130) between 3 h and 5 h, and 6% (n=27) > 6 h before parturition.

Table 2. Results of the monitored video-observation variables for all analyzed parturitions (n= 894) and the test set (n=444)

Variable	Number of calvings per score[1,2]				
	0	1	2	3	4
Moved to calving pen[3]	197 (96)	451 (233)			
Intervention[4] during calving	37 (13)	242 (118)	414(206)	197 (104)	4 (3)
Vitality calf[5]	610 (310)	189 (97)	32 (16)	15 (7)	

[1]Score refers to Table 1
[2]Results for the test set are presented in brackets
[3]Information recorded for 648 (329) calvings
[4]Information recorded for 894 (444) calvings
[5]Information recorded for 846 (430) calvings

Analyzing all animals from the test set (ALL) for the 12 d period, there was a significant increase in activity from day -8 onwards (116.4 ± 22.2/h) until calving, compared to day -12 (112.5 ± 23.7/h) and day -11 (113.3 ± 22.9/h). The greatest activity was found on the last day before calving (124.1 ± 27.4/h), as well as the shortest lying time (26.1 ±7.4 min/h). Rumination time was significantly shorter the last 7 days ante partum, compared to day -12 (21.5 ± 3.4 min/h), with the shortest rumination time (16.9 ± 4.9 min/h) on day -1.

For the 72 h period in ALL, there was an increase in activity every 12 h from -36 h ante partum until birth, with highest activity in the -12 h period preceding birth (124.8 ± 33.9/h). Lying time decreased significantly from -36 h (31.9 ± 8.3 min/h) to -24 h (29.0 ± 8.4 min/h) and -12 h (24.7 ± 9.1 min/h), where the shortest rumination time was found (14.0 ± 5.9 min/h).

During the 24h period in ALL, activity decreased continuously from -18 h (125.8 ± 42.5/h) to -6 h (118.3 ± 50/h). Afterwards, there was an increase at -4 h (128.0 ± 54.5/h) to -2 h (143.4 ± 44.7/h). Accordingly, lying time decrease from -6 h (26.1 ± 13.7 min/h) to -2 h (19.8 ± 11.3min/h), similar as rumination time (-6 h: 14.28 ± 9.1 min/h; -2 h: 6.1 ± 5.3 min/h).

The comparison of DIFF and NORM showed a significant difference in activity at the beginning of the 12 d period. Activity was greater in DIFF on day -12 (117.3 ± 20.8/h vs.111.18 ± 24.3/h) and on day -10 (117.4 ± 20.8/h vs. 111.9 ± 22.1/h). Furthermore, rumination time on day -12 was 6% shorter in DIFF compared with NORM. In the entire 72 h period rumination time was 7.6% shorter in DIFF(with the exception of -24 h). In the 24 h period, lying time was longer in DIFF at -16 h (30.6 ± 13.4 min/h vs 25.9 ± 12.7 min/h in NORM), but shorter at -4 h (21.0 ± 14.7 min/h vs. 24.2 ± 14.3 min/h). In this period, rumination time at -14 h to -6 h was 16.3% lower in DIFF compared with NORM group.

The comparison of cows that were moved to the calving pen (MOVED) and that calved in the close-up group (NOT MOVED) showed differences in the 12 d period from day -12 to day -8, where mean activity was 5.3% greater in MOVED. Also on day -1, MOVED had a greater activity (127.9 ± 28.8/h) than NOT MOVED (117.9 ± 22.6/h). A shorter rumination time was found on day -9, with 21.2 ± 3.3 min/h in MOVED versus 22.2 ± 3.3 min/h in NOT MOVED. In the 72 h period, MOVED showed a greater activity at -60 h (7.8%) and -12 h (11.9%), as well as 9.7% shorter lying time at -12 h. Analyzing the 24 h period, there was a greater activity at -12 h (+9.6%), -4 h (+18.6%) and -2 h (+15.2%) in MOVED. Furthermore, lying time in MOVED was 12.6 %, 16.7%, and 20.4% shorter at -16 h, -4 h and -2 h, respectively.

Based on the model with six input variables, the performance of the prediction algorithm was evaluated with the test data set. Table 3 summarizes the performance in the time period from 72 h to 1 h before the expulsion of the calf. The greatest accuracy was achieved at -12 h with 94% for the entire test set group and maintained on this level until the expulsion of the calf. The greatest sensitivity was achieved at -1 h before the expulsion of the calf (54%), the lowest at -72 h (19%), i.e. sensitivity increased with a shorter time to calving. This could be explained by the higher influence of the upcoming calving event on monitored variables just before the expulsion of the calf, in comparison to earlier periods.

Table 3. Results for the algorithm performance in the test set

Group	Parameter	Hours before calving						
		-72	-48	-24	-12	-6	-3	-1
All[1]	Accuracy	0.84	0.88	0.92	0.94	0.94	0.94	0.94
	Sensitivity	0.19	0.22	0.27	0.35	0.43	0.49	0.54
	Specificity	0.97	0.96	0.96	0.95	0.95	0.95	0.95
Moved[2]	Accuracy	0.82	0.87	0.90	0.92	0.92	0.93	0.93
	Sensitivity	0.22	0.24	0.28	0.34	0.40	0.43	0.46
	Specificity	0.96	0.95	0.94	0.94	0.93	0.93	0.93
Not moved[3]	Accuracy	0.82	0.87	0.92	0.94	0.95	0.95	0.95
	Sensitivity	0.15	0.17	0.23	0.32	0.38	0.45	0.50
	Specificity	0.98	0.97	0.97	0.96	0.96	0.96	0.96

[1]Includes all animals from the test set (n=444)
[2]Includes animals that were moved into the calving pen before giving birth (n=233)
[3]Includes animals that were not moved into the calving pen an gave birth in the close-up group (n=96)

Discussion

Rumination time

Various studies monitored peripartum rumination behavior with different devices, e.g. noseband pressure sensors (Braun et al. 2014; Pahl et al. 2014), microphone collars (Schirmann et al. 2013), electromyography (Büchel and Sundrum 2014) and ear attached accelerometers (Ouellet et al. 2016; Rutten et al. 2017). All studies showed decreasing rumination time with the upcoming calving event. Observing the long-term trend in our study, rumination time started to drop from day -7 onwards, which is in line with the findings by Soriani et al. (2012), Braun et al. (2014) and Clark et al. (2015), whereas Schirmann et al. (2013) and Borchers et al. (2017) did not find a significant decrease in rumination time in that time period. Considering the immediate time before calving, where we found a continuous decrease in rumination time from -6 h onwards, Pahl et al. (2014) also found a decrease starting at -6 h and being significant in the last 4 h antepartum. This is in accordance with Schirmann et al. (2013), who found a beginning decrease 4 h before expulsion of the calf. Also Büchel and Sundrum (2014) reported a significantly reduced rumination time in the last 6 h before the onset of calving. In summary, our findings are in line with previous reports and confirm that rumination time starts to descend moderately approximately one week before calving, followed by a distinct decrease immediately 4 to 8 hours before the expulsion of the calf.

Activity and lying time

Considering the 12 d period, dam's activity increased from day -8, with a peak on day -1. Borchers et al. (2017) observed a similar increase recorded by neck-collar attached sensors from day -4 on, compared to day -14. The general pattern in the last 24 h before calving, with an initial decrease of activity at -10, -8, and -6 h, and the following increase and peak towards the calving event, was similar to results by Borchers et al. (2017). They observed in primiparous cows a decrease and a nadir at 18 h before calving, followed by an increase and highest activity at 2 h ante partum.

In our study, shortest lying times were observed at the last day of the 12 d period. This was similar to Ouellet et al. (2016) and Titler et al. (2015), who found that lying time was significantly lower on the day of calving compared with day −4. During the 24 h period, there was a significant decrease in lying time from -6 h on, which is in relation with the rise in activity. The sensor-perceived increase of activity and the decrease of lying time reflects the oncoming restlessness during the cow's nestbuilding-like behavior, e.g. extensive olfactory check of the ground, straw pushing and licking of their own body (Wehrend et al. 2006), and change between lying and standing (Jensen 2012; Borchers et al. 2017). The particular drop in activity at -8 h might be related to the time when the cervix starts to open significantly in the first stage of labor (Breeveld-Dwarkasing et al. 2003), followed by the increase of activity and the transition to the second stage.

Assisted calvings

Comparing DIFF and NORM, the main difference was found in rumination time. The difference became more distinct from -14 h to -6 h, where DIFF had a 16.3% shorter rumination time than NORM. An earlier study found similar results, i.e. rumination time declined from -16 h more rapidly in cows with dystocia than with eutocia, with most pronounced differences in rumination time (3-fold shorter) at -8 h and -4 h (Kovacs et al. 2017). Interestingly, we found longer lying time in DIFF at -16 h, but shorter lying times at -4 h, compared with NORM. Proudfoot et al. (2009) described that cows with dystocia transitioned from standing to lying positions more frequently 24 h before calving than cows with eutocia (10.9 vs. 8.3 0.7 bouts/d). Similarly, (Barrier et al. 2012) showed that cows with assisted calving had a higher count of postural transitions during -4 to -2 h than unassisted cows.

Cow management

Furthermore, we analyzed differences in dams that calved in the prepartum group and in the calving pen. Reasons for not moving cows to the calving pen were additional work and tasks for the farm staff, such as prolonged calving assistance, providing first care to newborn calves, maintaining the feed alley, and others. Regrouping might increase competitive behavior and, thus, activity (Chebel et al. 2016). We found an increased activity at -12 h, -4 h and -2 h and a corresponding shorter lying time in MOVE group. Since the animals were moved into the calving pen on average 2 hours before the expulsion, these findings need further research. It can be speculated whether generally more active cows attracted more attention to the farm staff and, thus, were more often moved to the calving pen.

Performance of the model

Borchers et al. (2017) combined a neck and a leg accelerometer with a rumination microphone, and in combination with a neural network analysis, it was possible to predict the 8 h period before calving with 82.8% sensitivity and 80.4% specificity. Another study used an ear-attached accelerometer and recorded activity, rumination time and ear temperature (Rutten et al. 2017). In a 1 h window, the prediction model achieved a sensitivity of 21.2% and specificity of 99.1%, in a 12 h window 51% sensitivity and 99.4% specificity. Our model achieved for the 1 h window a sensitivity of 54% and specificity of 95%, and 35% sensitivity and 95% specificity in the 12 h window. It has to be mentioned that no information about the estimated day of calving was added into the test set. Moreover, we used a shorter surveillance period and hence, the trainings set used by the algorithm for adoption to cow individual behaviors was smaller compared to Rutten et al. (2017) (28 d vs. 9 to 12 d). The impact that some differences in study design can have is also shown by the comparison between MOVED and NOT MOVED in our study. Animals that were not moved to the calving pen had a greater accuracy and specificity in calving prediction compared with MOVED during the 24 h period.

Although we found a satisfying accuracy, the algorithm could be improved to, ideally, provide a long-term alert, e.g., 10 to 7 days before calving, and an immediate alert, e.g., 8 to 6 hours before onset of calving. Long-time alerts would enable a sufficient preparatory period e.g. for preventive measures and cow selection. Moving cows immediately before parturition can have negative effects on the animals (Proudfoot et al. 2013). Short-term alerts can help to enhance the focus on the beginning of the calving process itself and occurring complications.

Throughout the year, we conducted the study as consistently as possible. Nonetheless, extreme weather conditions (Moretti et al. 2017; Paudyal et al. 2016) as well as varying stock density in the close-up group can influence the cows' behavior (Lobeck-Luchterhand et al. 2015). Due to the complex management on commercial dairy farms, it was not possible to include non-pregnant (negative control) cows into the close-up group to mimic group dynamics in several situations; this could be tested in future studies. In follow-up studies the algorithm should be evaluated on different farms, on non- or early pregnant cows and heifers and under different calving systems. Finally, information about dystocia and other problems during calving should be included to the model to distinguish whether a cow needs calving assistance or not. This was beyond the scope of this study but will be a subject of further research.

Conclusion

This study shows that it is possible to accurately measure distinct behavioral changes that predict parturition in dairy cows by using an ear-attached accelerometer. The measured data of the variables activity, lying time and rumination time, as well as the added information on group level were successfully used to develop a model to predict the expulsion of the calf. Future refinement and improvement of the algorithm should aim on providing an alert system to predict the onset of calving with a great accuracy and to distinguish between dystocia and eutocia. Furthermore, our study showed that management factors, e.g. movement of cows, might have an effect on the performance of the algorithm, and thus, should be included in the model.

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