Veterinärmedizinische Universität Wien

Department für Nutztiere und öffentliches Gesundheitswesen in

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(Departmentsprecher: Univ.-Prof. Dr. med. vet. Michael Hess)

Universitätsklinik für Wiederkäuer

Abteilung für Bestandsbetreuung bei Wiederkäuern

(Leitung: Univ.-Prof. Dr. med. vet. Marc Drillich)

Evaluation of an accelerometer system for monitoring lying behavior in dairy calves housed indoor

Diplomarbeit

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Teresa Hoser

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Betreuer: Priv.-Doz. Dr. med. vet. Michael Iwersen

Universitätsklinik für Wiederkäuer

Abteilung Bestandsbetreuung

Gutachter: Ass.-Prof. Dr.med.vet. Johannes Baumgartner

Institut für Tierschutzwissenschaften und Tierhaltung

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Abbreviations

CCC	Concordance Correlation Coefficient
cm	Zentimeter
d	Days
ETK	Ethik- und Tierschutzkomission
g	G-Force
g	grams
h	Hours
HF	Holstein Friesian
HOBO	Hobo Data Logger
Hz	Hertz
κ	Cohen's Kappa Coefficient
MA	Massachusetts
m	Meters
ρ_C	Concordance Correlation Coefficient
QC	Quality Control
RC	Rapid Changes
r_S	Spearman Correlation Coefficient
SB	Smartbow
SD	Standard Deviation
Se	Sensitivity
Sp	Specificity

1 Introduction

Lying behavior in calves is considered as an indicator of their health status (Belaid et al. 2020; Borderas et al. 2009; Trénel et al. 2009). Hence, the monitoring of activity and measurement methods should therefore be of great interest for farmers as well as for veterinarians. The dairy industry has undergone major changes in the last decades; while the size of livestock increased, the number of farms decreased (Barkema et al. 2015), thus leading to a smaller time budget of the farmer for each animal (Frost et al. 1997; Madelrieux et al. 2008). Automated equipment (e.g. automated milking systems, feed pushers and manure scrapers), sophisticated sensor technologies and computer applications (e.g. herd management software) developed for livestock farming in the last decades, are used by farmers and their personnel to support their tasks (John et al. 2016; Marsh et al. 1993; Firk et al. 2002). Among other things, the use of these technologies aims to facilitate routine work and reduce working hours (Cournut et al. 2018; Barkema et al. 2015). By evaluating, improving, and using these technologies and software, the monitoring of animal welfare and health status is expected to be more feasible and less time consuming for the farmers.

The literature reports daily lying times of calves between 70% and 87.5% (16.8 – 21 h/d) (Wilson et al. 1999; Panivivat et al. 2004; Chua et al. 2002). Additional parameters are presented in Table 1.

Table 1. Overview: Activities of calves

Reference	Parameter	Calves[1] (n)	Observation period (h)	Proportion of observation period (%)
Wilson et al. (1999)	Lying	108 HF	216[2]	77.6 - 87.5
	Standing			28.1 - 36.3
	Self-grooming			16.7 - 48.3
	Tongue playing			2.2 - 7.1
	Investigative			8.8 - 28.5
	Chewing			3.5 - 14.8
Chua et al. (2002)	Lying	30 HF	168[3]	70.0
	Standing			4.8
	Moving			1.4
	Self-grooming			3.1
	Contact with pen			5.1
	Head out of pen			9.6
Panivivat et al. (2004)	Lying	60 HF	69[4]	73.2 - 81.0
	Standing			4.4 - 11.4
	Eating			1.4 - 5.5
	Drinking			1.0 - 1.6
	Self-grooming			2.6 - 4.4
	Investigating environment			0.2 - 2.9
	Contacting pen			2.7 - 9.0
Roland et al. (2018b)	Lying	15 HF	60[5]	57.9
	Standing			39.1
	Locomotion			2.9
	Feed intake			14.8
	Water intake			0.3
	Milk intake			1.4
	Ruminating			0.9

[1] HF: Holstein Friesian

[2] 9 tapes, each lasting 24h
[3] 7 days within 7 weeks (7x24h)
[4] 16h once weekly, over 6 weeks
[5] 4h for each calf

The level of activity is influenced, e.g. by the housing system shown by Jensen et al. (1998), who stated that calves kept in group pens had higher activity levels than calves in single pens, thus suggesting, that play behavior may be an indicator for welfare of the animals. Camiloti et al. (2012) reported that calves offered the choice for lying down either on bedding or on bare concrete, never laid down on the bare concrete. Furthermore, the dairy calves showed remarkable preference for drier sawdust as bedding material. Therefore, the before mentioned study indicates, that the possibility for the animals lying down on soft and dry bedding is important for growing calves. In this context, monitoring of resting times might be a reliable parameter for ensuring the comfort and health of calves. A positive correlation between the amount of resting time and the growth rate of heifers has been reported (Mogensen et al. 1997). Hänninen et al. (2005) also showed, that longer resting times in calves resulted in better growth rates of the animals. Detecting to what extent livestock has adapted to their environment, was also reported to be possible by collecting data on the rhythms of resting and activity (Ruckerbusch et al. 1975; Veissier et al. 1989). Borderas et al. (2008) described, that calves, experimentally infected with a low dose of bacterial endotoxin, showed lower activity while lying down, but their overall recumbency was not reduced. Additionally, the duration of rumination and hay intake, as well as frequency of self-grooming declined in the infected group of calves compared to the control group. Hence, the detection of these changes in behavior may help to identify the onset of disease.

Considering that direct and video observations are very time consuming (Müller et al. 2003; Firk et al. 2002) and are, especially for larger herds, nearly impossible to manage, various systems have been developed for animal monitoring. Accelerometers, which include pedometers, ear-tags, collars and sleep monitors as well as automated feeding systems (AFS) and other precision livestock farming technologies (PLT) have been developed for reliable and time-efficient detection of different behaviors in dairy calves (Costa et al. 2021; Swartz et al. 2016; Jensen et al. 2004). These systems have the potential for ensuring a continuous evaluation of well-being and health status of the animals. Pedometers have already been used for decades to detect cows in estrus (Firk et al. 2002; Liu et al. 1993; Arney et al. 1994). Using a three-dimensional accelerometer and a multiclass support vector machine, Martiskainen et al. (2009) measured several behavior patterns including lying (80% sensitivity; 65% precision) and standing (80% sensitivity, 65% precision) behavior in cows. Hill et al. (2017) also evaluated an ear attached accelerometer system (CowManager SensOor, Agis, Harmelen, The Netherlands), which recorded rumination, eating, and inactivity times in 6-week-old calves. The authors stated that the sensors delivered valid measurements for these behavior patterns, although correct ear placement of the sensors and considering their environment was shown to be crucial. The HOBO Pendant G accelerometer (Onset Computer Corporation, Bourne, MA, USA) was evaluated by Bonk et al. (2013). In their study, standing and lying behavior in dairy calves were examined and total lying times and bout frequencies of the animals with Pearson coefficient of correlation of $r = 99.9$ and a predictability, sensitivity, and specificity >97% compared to direct observation were reported. Roland et al. (2018b) developed and tested an algorithm for the tri-axial accelerometer system SMARTBOW (SB) to detect selected behaviors, such as postures, milk intake, water intake, solid feed intake, rumination, licking or sucking without milk intake and other behaviors in dairy calves. Video recordings were used to distinguish whether an activity was correctly recorded by the ear-tag with the developed algorithm. For posture (i.e. lying and standing) a sensitivity of 94.4%, specificity of 94.3%, precision of 95.8% and an accuracy of 94.3% were found. The SB ear-tag was therefore successful in detecting lying behavior with a Cohen's kappa (κ) of 0.88, indicating an "almost perfect agreement" (Landis and Koch 1977). Furthermore, this ear attached tri-axial accelerometer system has been evaluated in a pilot study for detecting drinking behavior in bucket-fed dairy calves (Roland et al. 2018a). The authors found a "substantial agreement" with $\kappa = 0.68$ between sensor and video analyses and stated, that more research on a larger number of animals is needed, e.g. to increase sensitivity (82.9%) and precision (60.4%). In adult cows, the system has already been used to detect and monitor rumination (Borchers et al. 2016; Reiter et al. 2018), estrus behavior (Schweinzer et al. 2019), localization of cows within a barn (Wolfger et al. 2017) and parturition (Krieger et al. 2018). Automated and continuous monitoring of lying times and lying bouts in calves can help to detect early changes in the individual lying behavior,

and hence give information about potential diseases in animals, or their adaption to an environment (Hänninen et al. 2005; Hixson et al. 2018; Swartz et al. 2017)
Using HOBO loggers, Sutherland et al. (2018) reported, that calves suffering from neonatal calf diarrhea tended to have a smaller number of lying bouts before clinical diagnosis, compared to healthy calves. Using the same sensor, Studds et al. (2018) found that calves with navel inflammation showed decreased lying times, compared to healthy calves. In the same study, it was shown, that the diarrhea status did not influence the number of lying bouts. Hanzlicek et al. (2010) stated, that animal activity, measured by pedometers and accelerometers, seems to be a promising indicator for early recognition of bovine respiratory disease. In their study, the percentage of lying-down time per calf increased on day 4 after inoculation, compared to the percentage prior to induction of pneumonia.

The primary objective of this study was to evaluate the ear-attached 3-D accelerometer system SB (Smartbow GmbH, Weibern, Austria) for detecting lying and standing behavior in dairy calves housed indoor, in comparison with the current sensor “gold standard”, the HOBO logger.

2 Materials and Methods

The study was performed on a commercial Slovakian dairy farm in December 2019. All study procedures were discussed and approved by the institutional ethics and welfare committee (ETK-11/09/2017) and by the Slovakian Regional Veterinary Food Administration.

2.1 Animals, Housing & Feeding

Calves on the dairy farm are kept in a barn consisting of 6 pens (pen size 13.5m x 7.7m), in which the calves were grouped by age. Depending on growth rate, on average, calves were regrouped every 10 days and spent 10 weeks in the facility in total.
For the study, 50 weaned Holstein-Friesian calves of approximately 4 months of age were used. The study period was split up in to two identical phases, due to limited availability of HOBO loggers. For each of both phases, 25 animals were randomly selected from the barn and put into one pen for the study period. During both study phases, calves were bedded on straw and had ad libitum access to food and water. The animals were fed twice a day with total mixed ration, consisting of grass silage, corn silage, concentrates and minerals. A headlock with 12 positions was installed as feed front; the size of the water trough was 2 meters.

2.2 Study Design

Standing and lying times of each calve were recorded with SB ear-tags (SB GmbH, Weibern, Austria), HOBO data loggers (HOBO Pendant G Acceleration Data Logger, Onset Computer Corporation, Bourne, MA) and video cameras over the period of 5 to 7 days simultaneously. For reliable comparison, all systems were synchronized in time once a day by use of a Windows time server (Windows Server 2012 R2, Microsoft Coporation). HOBO loggers (i.e. an accelerometer with included gyroscope) have been used in a previous study to detect resting and activity patterns in dairy calves (Bonk et al. 2013), and were thus chosen as reference in our study. Video material and the following analyses were used for random checks of the HOBO loggers and upon “rapid changes” (RC), defined as short-term changes in standing and lying times of less than 3 minutes. The animals were checked at least twice a day for possible impairment of health and well-being due to the application of the sensors (e.g. swelling of the leg, lameness). In total, 25 HOBO loggers were available resulting in conducting data collection 2 study periods.

2.3 Smartbow System

The calves were equipped with the accelerometer-based ear-tag SB (size 52 x 36 x 17; weight 34 g;) approximately one month prior to the start of the trial. The ear-tags (placed in the middle of the right ear) determined three-dimensional (x-,y- and z- axis) acceleration data (10 Hz, i.e. 10 values per second), which were sent in real-time to the receiver system (SB WallPoint), installed throughout the study barn, and further transmitted to the local server (SB FarmServer). For study purposes, the raw data was processed by the SB company and classified as “standing” (1), “lying” (0) or “undefined” on a minute basis for each calf. Classification of standing and lying behavior (i.e. standing =1; lying = 0) per calf and minute were considered as valid by the SB company, if more than 30 acceleration values were available in this specific minute.

2.4 HOBO

In our study, HOBO loggers were attached to the left hind leg of the calves, medial in the distal one-third of the metatarsus by using a self-adhesive bandage (CoFlexVet, Andover Healthcare, Inc., Salisbury, MA, USA) as previously described by Ito et al. (2009). Before attaching the HOBO logger to the leg, it was embedded in a foam cover (25x10x1cm) to reduce the risk of pressure marks on the legs. The HOBO logger records the *g*-forces of the x, y, and z-axes. Acceleration on the y-axis was used to distinguish between standing (≤ 2.55 *g*) and lying (> 2.55 *g*) position. To transform all *g*-forces into positive values, a constant (3.2 *g*) was added, as previously described by Ledgerwood et al. (2010). Furthermore, the *g*-forces were also converted by the HOBO software (Onset Computer Corporation, 3.7.21) into angles of tilt. As previously reported by Ito et al. (2009), calves exhibiting a tilt of ≥ 60° of the vertical axis (y-axis), measured by the HOBO, were considered as “lying”. Consequently, tilt of the vertical axis < 60° was considered as “standing”.

2.5 Video Recording

Four cameras with integrated infrared illuminators (IR Bullet Network Camera Version DS-2CD2632F- I(S), Hikvision, Hangzhou, China) were installed, each in one corner of the study pen with the 25 animals at a height of about 4 meters. To ensure reliable recordings during nighttime, a light source was installed on the ceiling of the barn. Identification of the animals was ensured by marking each animal with a unique number ranging from 1 to 50 on both sides of the croup, between tuber coxae and tuber ischiadicum, with a commercially available cattle marker (Animal Marking Crayon, RAIDEX GmbH, Dettingen, Germany).

2.6 HOBO and SB data

Quality control (QC) of the HOBO dataset was performed by a python script (Python Software Foundation, Python 3.7.9, pandas 1.2.0 available at python.org), which was based on a macro by Ledgerwood et al. (2010), eliminating possibly erroneous data. The SB company delivered a classified and validity checked dataset (see 2.3), which was based on raw data (i.e. x-, y- and z-accelerations) recorded by the SB ear-tags. Information for each minute, from HOBO and SB, were useable when the required data for 60 seconds were given by the sensors.

For each minute, in which both, HOBO and SB data were available, the datasets were merged, resulting in the final amount of 265,635 datapoints, for HOBO and SB, each. Additionally, events, such as short-term changes, were also counted for HOBO and SB. To evaluate to what extent the "undefined" minutes reported by SB (see 2.3) had an impact on study results, a second dataset for SB was created by eliminating all minutes not being defined as "standing" (1) or "lying" (1) and re-merging it with the HOBO dataset.

2.7 Video Analyses

To validate data cleansing (i.e. the elimination of RC as described in 2.2) of the HOBO dataset and furthermore, to give an insight on the animal activity, video analyses was performed by one trained observer. Out of all events, that were standing and lying bouts under 3 minutes (defined as RC), registered by HOBO and SB, random samples out of the corresponding video footage were taken.

Therefore 120 video sequences based on 120 random samples (60 from SB and 60 from HOBO dataset) were analysed. Each sequence lasted 6 minutes, resulting in 720 minutes of video analyses of individual animal movement.
An animal was registered as lying by the observer, when all 4 legs were relieved, while standing was defined when at least three legs touched the ground.

In total, 21 different animals were analysed from the HOBO dataset and 23 different animals from the SB dataset. For analyzing the random video samples, the QuickTime Player Version 10.5 (1015.2.1, Apple Inc., Cupertino, California, USA) was used and all 4-camera perspectives were displayed simultaneously.

2.8 Statistical Analyses

For statistical analyses, data was transferred to Microsoft Excel Spreadsheets (Excel 2021, 16.46, Microsoft Corporation, Redmond, Washington, USA) and later processed employing SPSS (Version 24, IBM Corporation, Armonk, NY, USA). As described for SB, likewise for HOBO, lying was associated with the value “0”, while standing was associated with the value “1”, culminating in 60 values per hour per individual calf. Spearman correlation coefficients, Cohen’s kappa coefficients and concordance correlation coefficients (CCC) were calculated for comparison of SB and HOBO. Furthermore, the test characteristics sensitivity, specificity, positive predictive value, accuracy, and error rate were calculated for SB based on HOBO as the gold standard. Excluding all “undefined” minutes of SB, the correlation coefficients were re-calculated. To compare the two thresholds of the HOBO logger, *g*-force and angles of tilt, for posture classification, Spearman, Cohen’s kappa and CCC were also calculated for those.
In addition, comparisons of lying and standing times detected by SB and HOBO, were graphically evaluated by creating plots as described by Bland and Altmann (1986). Statistical significance for all tests was defined as $P < 0.05$.

3 Results

In total, 50 animals were enrolled in the study. After an average of 106.84 hours (SD = 49.15h) of data collection for each calve, the HOBO loggers were read out using the HOBOware software (Onset Computer Corporation). Due to HOBO logger-induced swelling of the hind legs, loggers had to be removed in some instances (17 calves**,** between 19h to 26h missing). In a single case, the animal was only identified as lying (0) by HOBO over the entire period of the study. Analyses of the respective video recordings of this particular animal led to its exclusion from the study, since an incorrect fixation of the logger could not be ruled out. Another animal had to be excluded, caused by one malfunctioning SB ear-tag. Hence, validity checked data by the SB company of 49 animals were available.

In the final analyses, data of 48 calves were considered. Both systems (i.e. SB and HOBO) were used simultaneously to record the standing and lying behavior of the calves in one-minute intervals. QC of HOBO data was performed by use of a python script based on a macro described by Ledgerwood et al. (2010), eliminating possibly erroneous data in the HOBO dataset. After QC and merging data, a total of 268,216 HOBO and SB datapoints from 48 individual animals remained for statistical analyses. The average observation time per calve was 93.13h (SD = 41.97h).

As shown in Table 2, for both HOBO methods, HOBO_ANG (angles of tilt) and HOBO_ACC (*g*-force), the amount of datapoints associated with lying times exceeded those associated with standing times, while the SB ear-tags revealed the opposite. The SB ear-tag determined a total of 151,721 and 113,893 minutes for standing and lying times of the animals, respectively.

2,602 minutes were classified as “undefined” by the SB system. One minute was defined as “undefined”, when the ear-tag was incapable of distinguishing between the animal standing or lying. To determine the influence of these "undefined" events on the results, the analyses were performed including and excluding these events (Table 2).

Table 2. Overview of total standing and lying times (min) detected by SB and 2 different HOBO measures

	Including undefined[3]				Excluding undefined		
	Standing	**Lying**	**Undefined**	**Total**	**Standing**	**Lying**	**Total**
HOBO_ANG[1]	104,499	163,717	0	268,216	103,697	161,917	265,614
HOBO_ACC[2]	104,410	163,806	0	268,216	103,609	162,005	265,614
SB	151,721	113,893	2,602	268,216	151,721	113,893	265,614

[1]HOBO_ANG: Standing and lying times detected by the HOBO angle
[2]HOBO_ACC: Standing and lying times detected by HOBO acceleration
[3]incapeability of the SB system to distinguish between standing and lying

After exclusion, 265,614 datapoints (i.e. 92.23h per calve on average, SD = 41.44h) remained in the analyses. Consequently, the number of lying and standing decreased for HOBO_ANG and HOBO_ACC, while the ratios between standing and lying times (for HOBO_ANG standing: lying including undefined 104,499min: 163,717min; excluding undefined: 103,697min: 161,917 min) did not differ significantly.

The correlations between HOBO_ANG and HOBO_ACC showed an "almost perfect agreement (Altman 1991) with a Concordance Correlation Coefficient (ρ_C) of 0.99 (Table 3).

Table 3. Correlations and agreements between HOBO_ANG and HOBO_ACC

	N(min)	**Spearman correlation (r_S)**	**Cohen's kappa (κ)**	**CCC (ρ_C)**
HOBO_ANG[1] vs. HOBO_ACC[2]	265,635	0.99**	0.99**	0.99**

**$P < 0.01$
[1] angles of tilt
[2] *g*-forces (acceleration)

3.1 Video analyses of HOBO and SB data cleansing

For each calf, an average of 51.2h (i.e., 6.3 days) of video footage was recorded. In total, 3,780 hours (4 cameras, 945 animal hours per camera) of video observation were available for analyses. Therefore, one hour corresponds to the movement of one animal out of one camera perspectives. The video data were used to determine the potential causes for RC, i.e. short lying and standing bouts of less than 3 min within a longer standing and lying phase. In addition to providing information on the animal behavior, this analyses was employed for data cleansing approaches. Analysing 24 animals, from the second group, 3618 hours of video footage of animal movement were taken in account for statistical analyses.

Table 4. Events associated with misclassifications of standing and lying events

	HOBO	SB
Number of events, classified as RC	60	60
Algorithm corrected lying bout (< 3min) to standing	**31**	**34**
Algorithm appliance correct	31	21
Feeding fence	10	10
Standing up	8	1
Head movement	0	8
Leg movement	3	0
Wants to lie down on another calve	1	0
People in the barn, calves run around	1	1
Urinating	0	1
No special behavior identifiable	8	0
Algorithm appliance incorrect	0	13
Head movement	0	5
Lying down	0	1
No special behavior identifiable	0	7
Algorithm corrected standing bout (< 3min) to lying	**29**	**26**
Algorithm appliance correct	16	25
Lying down	16	0
Head movement	0	7
Body movement	0	6
No special behavior identifiable	0	12
Algorithm appliance incorrect	13	1
Standing up	7	0
Feeding fence	1	0
Head movement	0	1
No special behavior identifiable	5	0

The video analyses on the HOBO dataset for lying bouts under 3 minutes, revealed a correct application for all 31 events (i.e. 100%). RC were mostly associated with the animal standing in the headlock of the feeding fence and with the animal being in the process of standing up. For SB, in the case of lying bouts under 3 minutes, video analyses revealed 21 true corrections (i.e. 61.8%) of the algorithm. Most of these RC were associated with the animal standing in the headlock of the feeding fence or head movement. Considering all corrected standing bouts under 3 minutes (i.e. 29), in the HOBO dataset, 16 (i.e. 55.2%) cases were revealed as true corrections of algorithm appliance, checked by video analyses. All of these events were associated with the animal being in the process of lying down. The algorithm appliance on the SB dataset for standing bouts of under 3 minutes delivered a true correction in 25 of 26 cases (i.e. 96.1%). Most of these RC in the SB dataset were associated with head and body movements of the animal.

3.2 Comparison of standing and lying events before and after QC

The effect of data cleansing on average standing and lying times of the calves is presented in Table 5. Data cleansing and QC includes the algorithm appliance, eliminating RC. Additionally, the algorithm, eliminating RC, was experimentally applied on the SB dataset, to see if the outcome would benefit from including this step in the QC. The final comparison between the SB and HOBO dataset was performed with the SB dataset, as delivered by the SB company (no elimination of RC).

Table 5. Comparison number and duration of events* on average per calve before and after excluding RC

	HOBO		SB	
	including RC	excluding RC	including RC	excluding RC
Standing Events (n)	102	56	84	65
Average duration (min)	23	43	37	47
Lying Events (n)	102	56	84	66
Average duration (min)	39	71	28	36

*Only complete events were considered, excluding “undefined” events

The number of lying and standing events decreased, for SB to a lesser extent than for HOBO. In most cases, the average times per standing and lying event increased, for both, HOBO and SB. Conversely, the average lying time per calve decreased for HOBO. Consequently, more RC during longer lying times were registered and corrected by the algorithm.

3.3 Correlation between the lying times detected by HOBO and SB

Finally, the cleansed data collected by HOBO and SB were compared (Table 6). The minutes defined by SB as “undefined” were considered as “false negative” (animal standing), if HOBO classification revealed the animal as lying (0), or “false positive” (animal lying), if HOBO classification revealed the animal as standing (1). By assuming this "worst case" scenario, the non-decision-making capability of SB, defining an animal as “undefined” additionally to “lying” (0) and “standing” (1), should be taken into account and a possible favoritism avoided.

Table 6. Comparison of HOBO vs. SB (values in minutes)

	SB					
	including undefined			**excluding undefined**		
HOBO	**Lying**	**Standing**	**Total**	**Lying**	**Standing**	**Total**
Lying	112,668	51,050	163,718	112,667	492,50	161,917
Standing	2,028	102,471	104,499	1,226	102,471	103,697
Total	114,696	153,521	268,217	113,893	151,721	265,614

Various performance related test characteristics for SB were calculated by comparing the detection of standing and lying events to the results of HOBO (Table 7). Sensitivity (Se) and Specificity (Sp) in detecting lying events by SB was 68.8% and 98.1%, respectively. The calculated positive predictive value (PPV), i.e. the probability of the system to detect an animal as lying, was approximately 98%. Accuracy was at approximately 80%, while the error rate was about 1.8%. All parameters improved for the dataset by excluding all “undefined” events.

Table 7. Parameters used for evaluating the performance of the SB System

Parameter	Results in % including "undefined"	Results in % excluding "undefined"
Sensitivity[1]	68.8	69.6
Specificity[2]	98.1	98.8
Positive predictive value (PPV)[3]	98.2	98.9
Accuracy[4]	80.2	81.0
Error rate (ER)[5]	1.8	1.1

[1] True Positive / (True Positive + False Negative) x 100
[2] True Negative / (True Negative + False Positive) x 100
[3] True Positive / (True Positive + False Positive) x 100
[4] True Positive + True Negative / (True Positive +True Negative + False Positive + False Negative) x 100
[5] False Positive / (False Positive + True Positive) x 100

Finally, the correlation between the two systems, HOBO and SB, based on 268,216 (including undefined) and 265,614 (excluding undefined) minutes, were calculated (Table 8). The Spearman correlation(r_S) was 0.65 stating a 'strong correlation' (Cohen 1988). Cohen's Kappa (κ) of 0.62 indicates a „substantial agreement" (Landis and Koch 1977) to "good agreement" (Altmann 1991). The Concordance correlation coefficient (ρ_C) showed a 'poor correlation' (McBride 2005), with $\rho_C = 0.55$. All correlations and agreements improved, after excluding the undefined minutes from the dataset (Table 8, $P < 0.01$, for all comparisons).

Table 8. Correlations between HOBO and SB

HOBO vs. SB	N (min)	Spearman correlation (r_S)	Cohen's kappa (κ)	CCC (ρ_C)
including "undefined"	268,216	0.66	0.62	0.55
excluding "undefined"	265,614	0.67	0.63	0.63

The agreement of lying times, detected by SB and HOBO, is shown as a Bland-Altman plot (Bland and Altman 1986) in Figure 1. Minutes, which were classified by the SB algorithm as "undefined" were excluded.

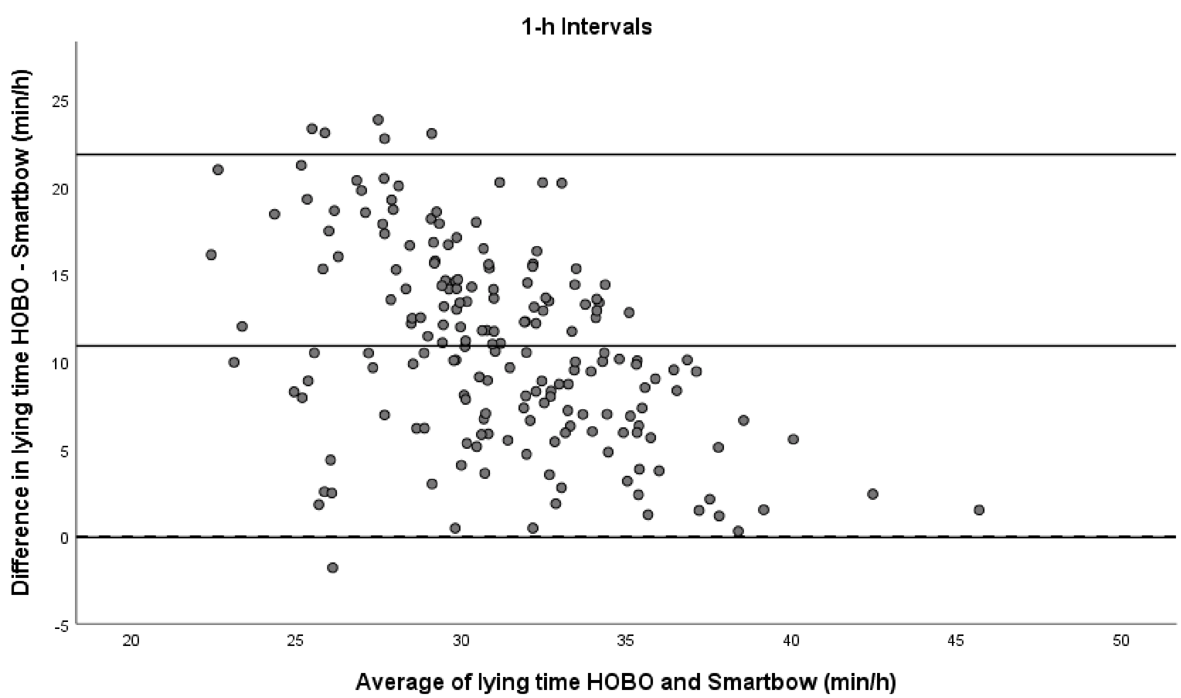

Figure 1. Differences of the detected lying times of SB and HOBO to their mean. Data of 48 animals of, in total ,186 24-h periods are shown (min/h). The dotted line marks zero. The intermediate solid line indicates the mean while the upper and lower solid line mark the mean ± 1.96 SD.

SB underestimated lying time minutes by an average of 10.91 minutes per hour, compared to the means of both systems. The 95 % confidence interval (CI) ranged from -0.05 min to 21.86 min per hour.

4 Discussion

In this study, the performance of the SB ear-tag and its algorithm for detecting lying and standing behavior in calves was evaluated by comparison with already established HOBO logger (Bonk et al. 2013; Swartz et al. 2016; Sutherland et al. 2018). The algorithm used in this study was originally developed by the SB company for detecting posture in dairy cows.

A similar study was conducted by Roland et al. (2018b) on a smaller number of animals by using a specifically developed algorithm for calves, which is not commercially available, thus limiting the comparison of the results.

As a secondary objective, the QC and thresholds (elimination of RC and choice of logger output) for HOBO, which were already used in several studies (Martiskainen et al. 2009; Ledgerwood et al. 2010), were evaluated by video observation.

Previously, Ledgerwood et al. (2010) stated, that the choice of the HOBO logger output does not affect the outcome. HOBO delivers data in terms of *g*-forces. These *g*-forces can be transformed into angles of tilt. The correlations and agreement between HOBO_ACC (*g*-force) and HOBO_ANG (angles of tilt) in this study showed an “almost perfect agreement” (Landis and Koch 1977), confirming that the logger output is a “user’s choice” (Ledgerwood et al. 2010) and the thresholds of the two output variables of HOBO deliver the same classification of lying and standing behaviors.

RC, i.e. standing and lying bouts under 3 minutes during a longer standing or lying period, were checked by video analyses to validate the algorithm appliance on the HOBO dataset. This procedure was also applied experimentally on the SB dataset. To our knowledge, the influence of the use of this algorithm in course of QC of the HOBO data has not been evaluated previously.

Video analyses of 120 random samples of RC, 60 for each, HOBO and SB, showed a high efficiency, in terms of true corrections, of the algorithm appliance on the two datasets. The algorithm described by Ledgerwood et al. (2010) for QC by eliminating RC in the HOBO dataset, resulted in improved data quality. The method is therefore considered valid. RC that occurred during a longer standing period were eliminated more reliably by the correction algorithm, compared to RC occurring during a longer lying period (100% vs. 55.2%). Therefore, RC during longer standing periods were more likely to be a “false correction” of the algorithm. This might be due to the possibility, that a calf standing has a wider activity radius, than a calf lying.

By applying the correction algorithm on the SB dataset, the elimination of the RC also revealed a high efficiency (in total, 76.7% correct algorithm appliances in a sample of 60 RC), although the SB data did not undergo our own QC in the final comparison. Based on our findings, SB may profit in the QC by including the step of RC elimination. Overall, the usage of this algorithm eliminating RC delivers a useful outcome on the HOBO (in total 87.3% correct algorithm appliances in a sample of 60 RC) and, given our findings, also on the SB dataset.

The reasons for RC in HOBO data are mostly associated with the animal standing in the feeding fence, which might lead the animal to sway their hind legs, where the HOBO logger is fixated, as we observed during video footage analyses. RC, detected by the SB ear-tag, were also likely to be associated with the animal standing inside the feeding fence, caused by the head being in a down right position and therefore, the SB ear-tag being closer to the floor, as well as the possible ear movements. Out of 60 RC in the SB dataset, 19 were not associated with specific behaviors (Table 4), indicating that the SB classification algorithm might profit from further research and enhancement.

After algorithm appliance, the number of lying events for HOBO decreased by 54.9% (102 events before, 56 events after), while the general lying time per bout increased by 182.1% (39min to 71min). The average duration of a lying bout for a calf in our study, detected by SB (including RC) was 28 minutes. Roland et al. (2018b) detected with the SB ear-tag 33 minutes on average per lying bout. However, it should be mentioned that the study of Roland et al. (2018b) used younger calves and observations periods of 4 hours per calf (n=15) with deliberately higher calf activity in the morning hours.

The final comparison of lying times in our study, detected by HOBO and SB, revealed significant differences between the two methods. The total percentage of lying time detected by SB over the entire study period was 42.5% (including undefined; excluding undefined: 42.9%) being significantly lower, than those reported by previous studies with lying times between 57.9% - 87.5% (Panivivat et al. 2004; Wilson et al. 1999; Roland et al. 2018b; Chua et al. 2002). Considering the entire study period, a lying time of 61.0% (SB: 42.5%) was determined using the HOBO logger. This corresponds to an average lying time per day and calf of 14.5h and is lower than the values determined by Bonk et al. (2013) with approx. 75% (i.e. 18h/d). Sutherland et al. (2018) reported similar lying times per day with 69 - 73% (i.e. 16.7h-17.5h/d) by using HOBO in their study.

The average duration of 71 min per lying bout determined by HOBO (SB: 28 min including RC) was higher than the duration of 54 min reported by Bonk et al. (2013). Swartz et al. (2016), who also used HOBO, determined an average duration per lying bouts of approximately 41.4min (within observation periods of 7h). Although calves were observed in all previously mentioned studies, the age of the animals was different, which could be the reason for the differences in lying bouts duration. Furthermore, the different housing conditions may also cause an influence on the determined lying times, as the housing conditions have previously been associated with different activity patterns in calves (Jensen et al. 1998).

Test characteristics for SB, based on HOBO classifications as gold standard, revealed a sensitivity of 68.8% for detecting lying behavior. Roland et al. (2018b) found a sensitivity of 94.4% in their study for posture (i.e. lying vs. standing or locomotion) classification by SB. The agreement in SB based detection of standing and lying behavior compared with video analyses was lower in our study with κ =0.62 (κ =0.63 when excluding all "undefined" events) than in Roland et al. (2018b), who reported a Cohen's kappa of 0.88. In this regard, it should be noted that the algorithm used in our study was developed by the SB company for use in dairy cows and not for calves. From this, it can be concluded that age-specific algorithms must be developed when accelerometers are used to detect body posture. Using the algorithm developed for cows does not account for age-specific differences in animal behavior, as stated by Jensen et al. (1998) that "juveniles are highly motivated to play". The algorithm developed for cows is obviously not able to distinguish between play behavior and the faster movement changes of calves compared to the more sluggish lying down behavior in cows.

The approach taken by Roland et al. (2018b) to develop algorithms specifically for calves should be continued and refined, if the SB system is to be used in practice or research. Further development of the algorithms is also necessary in that Roland et al. (2018b) used only 15 pre-weaned calves in their study and video observations of 4h, each. In contrast, in our study, 48 weaned calves were housed in a larger group pen and followed for a longer period at different housing conditions.

When using other sensor technologies, valid detection of lying and standing has been reported. Trénel et al. (2009) reported a mean sensitivity of 99.6% and a specificity of 98.0% for the detection of lying behavior, using the leg-mounted accelerometer device IceTag (http://www.icerobotics.com). In this study, video recordings were used as the gold standard. Using the ear-mounted CowManager SensOr system (Agis, Harmelen, the Netherlands), Hill et al. (2017) were able to detect inactive periods with a regression coefficient (R^2) of 0.97 compared to live observation.
In our study, the SB ear-tag was not able to detect the calfs' posture (i.e., lying or standing) with sufficient accuracy in real-time. In terms of real-time posture detection, Roland et al. (2018b) found a similar result.
The reason why the SB system classified a large number of postures as "undefined" in addition to the classification of standing and lying behaviors, could not be conclusively clarified. Further development of the algorithm is also necessary in this regard.

As shown in the Bland Altmann plot in Figure 1, SB underestimated lying times on average by 10 minutes per calf and hour. Hence, on a 24h basis, lying times per calf might be underestimated by 240 minutes and day. This difference is relevant from a practical and veterinary perspective for assessing animal behavior and is not negligible.

5 Conclusion

Considering the results of our study, the SB system using the algorithm developed for cows, is not able to provide reliable information about lying behavior in calves in real time. To use the SB system in calves, it would be crucial to develop an algorithm specifically for calves and re-evaluating the steps of QC (including elimination of RC) as well as re-evaluating the system to define an animal as “undefined” additionally to “lying” and “standing”.
Based on the video analyses, it was further possible to validate the algorithm described by Ledgerwood (2010) for the correction of HOBO-based rapid position changes. The application of the algorithm leads to improved data quality and can therefore be recommended. Both outcome variables of the HOBO logger, the g-forces and angles of tilt, can be used equally for the assessment of standing and lying in calves.

6 Summary

Lying behavior in calves is considered as an indicator of their health status (Belaid et al. 2020; Borderas et al. 2009; Trénel et al. 2009). Hence, monitoring of posture and activity measures of the animals should be of great interest for farmers as well as for veterinarians.

Considering that direct and video observations are time consuming and are, especially for larger herds, nearly impossible to manage, various systems have been developed for animal monitoring. These systems have the potential for ensuring a continuous evaluation of well-being and health status of the animals. The HOBO Pendant G logger (Onset Computer Corporation, Bourne, MA) was previously evaluated by Bonk et al. (2013) for detecting standing and lying behavior in dairy calves, with a sensitivity, and specificity >97% compared to direct animal observation. Roland et al. (2018b) developed and tested an algorithm for the tri-axial accelerometer system SMARTBOW (Smartbow GmbH, Weibern, Austria) to detect selected behaviors, such as lying and standing, with a sensitivity of 94.4%, a specificity of 94.3%. The comparability of our results with the results of Roland et al. (218b) is limited by the fact, that in their study, a specific algorithm for calves was developed, which is not commercially available yet.

In our study, the acceleration sensor system SMARTBOW developed for cows was evaluated for recording the lying and standing behavior of calves. For comparison, the previously described HOBO Logger was used as the gold standard.

Further objectives of the study were the validation of Ledgerwood's et al. (2010) proposed correction algorithm to eliminate rapid position changes in the HOBO logger data and the evaluation of the HOBO-based *g*-forces and angles of tilt to detect standing and lying behavior in calves. The evaluation was carried out based on video recordings.

The study was performed on a commercial Slovakian dairy farm in December 2019. 50 weaned Holstein-Friesian calves of approximately 4 months of age were enrolled in the study. The calves were kept in a barn consisting of 6 pens (pen size 13.5m x 7.7m). For statistical analyses, Spearman correlation coefficients, Cohen’s kappa coefficients and concordance correlation coefficients were calculated for comparison of SB and

HOBO. Furthermore, the test characteristics sensitivity, specificity, positive predictive value, accuracy, and error rate were calculated for SB based on HOBO as reference. The comparison of the lying times detected by HOBO and SB revealed significant differences between both methods. Sensitivity for SB, to detect lying behavior, was calculated as 68.8%. Cohen's kappa of 0.62 (0.63 for the dataset excluding all "undefined" events) for detecting standing and lying behavior by SB showed a lower association with video observations, compared to Cohen's kappa of 0.88 reported by Roland et al. (2018b). Graphical comparison of SB and HOBO using the procedure as recommended by Bland and Altman (1986) revealed an average underestimation of 10 minutes for the hour-based lying times. Hence, on a 24h basis, lying times per calf might be underestimated by 240 minutes and day. This difference is relevant from a practical and veterinary perspective for assessing animal behavior and is not negligible.
The agreement between the two HOBO logger outputs, *g*-force and angles of tilt, showed an "almost perfect agreement" (Landis and Koch 1977), confirming that the logger output is "a user's choice" as stated by Ledgerwood et al. (2010). Furthermore, video analyses of 120 random samples of "rapid changes" (i.e., standing and lying periods of less than 3 minutes during a prolonged standing or lying period) showed high efficiency of the algorithm proposed by Ledgerwood et al. (2010) for eliminating erroneous data sequences in the HOBO and SB data sets. The application of the algorithm leads to improved data quality and can therefore be recommended.

Considering the results of our study, the SB system using the algorithm developed for cows is not able to provide reliable information about lying behavior in calves in real time. To use the SB system in calves, it would be crucial to develop an algorithm specifically for calves and re-evaluating the steps of quality control (including elimination of rapid changes) as well as re-evaluating the system to define an animal as "undefined" additionally to "lying" and "standing".

7 Zusammenfassung

Die Beurteilung des Liegeverhaltens von Kälbern gilt als guter Indikator zur Beurteilung ihres Gesundheitszustands (Belaid et al. 2020; Borderas et al. 2009; Trénel et al. 2009). Das Monitoring der Körperposition sowie der Tieraktivität ist daher sowohl für LandwirtInnen als auch für TierärztInnen von großem Interesse. Da die direkte Tierbeobachtung und auch die Auswertung von Videos zeitaufwändig und, vor allem in größeren Herden, kaum zu bewerkstelligen sind, wurden verschiedene automatisierte Systeme zur individuellen Überwachung von Tieren entwickelt. Diese Systeme haben das Potenzial, eine kontinuierliche Erfassung von Parametern zu ermöglichen, die zur Beurteilung des tierindividuellen Wohlbefindens und des Gesundheitszustands herangezogen werden können.
Der HOBO Pendant G-Logger (Onset Computer Corporation, Bourne, MA, USA) wurde kürzlich von Bonk et al. (2013) zur Erkennung des Steh- und Liegeverhaltens bei Kälbern mit einer Sensitivität und Spezifität > 97% im Vergleich zur direkten Tierbeobachtung evaluiert. Roland et al. (2018b) entwickelten und testeten einen Algorithmus für das tri-axiale Beschleunigungssensorsystem SMARTBOW (Smartbow GmbH, Weibern, Austria) zur Erkennung spezifischer Verhaltensweisen. Für das Merkmal „Körperhaltung“ (das u.a. Stehen und Liegen beinhaltet) ermittelten die AutorInnen eine Sensitivität von 94,4% und Spezifität von 94,3%. Aufgrund der verschiedenen Merkmalsdefinitionen sowie die Verwendung eines eigens für Kälber entwickelten Algorithmus durch Roland et al (2018b), der kommerziell nicht zur Verfügung steht, ist der direkte Vergleich mit unseren Studienergebnissen nur eingeschränkt möglich.

In unserer Studie wurde das für Kühe entwickelte Sensorsystem SMARTBOW zur Erkennung des Liege- und Stehverhaltens von Kälbern evaluiert. Zu Vergleichszwecken wurde der zuvor beschriebene HOBO Logger als „Goldstandard“ verwendet. Weitere Ziele der Studie waren die Validierung des von Ledgerwood et al. (2010) vorgeschlagenen Korrekturalgorithmus zur Eliminierung schneller Positionsänderungen in den Daten der HOBO-Logger und die Beurteilung der HOBO-basierten *g*-Kräfte und

Neigungswinkel zur Erkennung von Steh- und Liegeverhalten bei Kälbern. Hierzu wurden Videoaufzeichnungen analysiert und zur Beurteilung verwendet.
Die Studie wurde im Dezember 2019 auf einem kommerziellen slowakischen Milchviehbetrieb durchgeführt. In die Studie wurden 50 abgesetzte Holstein-Friesian-Kälber im Alter von ca. 4 Monaten aufgenommen. Die Kälber wurden in einem Stall mit 6 Gruppenbuchten (jeweilige Buchtgröße 13,5 m x 7,7 m) gehalten.

In der statistischen Auswertung wurden Spearman-Korrelationskoeffizienten, Cohen's Kappa-Koeffizienten (κ) und Konkordanz-Korrelationskoeffizienten für die jeweiligen Vergleiche zwischen SB und HOBO berechnet. Weiterhin wurden die Testcharakteristika Sensitivität, Spezifität, positiver prädiktiver Wert, Genauigkeit und die Fehlerquote für SB auf der Grundlage von HOBO als „Goldstandard" berechnet.

Der Vergleich der von HOBO und SB ermittelten Liegezeiten ergab signifikante Unterschiede zwischen beiden Methoden. Für das SB System wurde eine Sensitivität zur Erkennung von Liegen von 68,8 % ermittelt. Cohen‘s Kappa betrug 0,62 (0,63 bei Ausschluss aller als "undefiniert" klassifizierten Ereignisse) und wies eine geringere Übereinstimmung im Vergleich zu Roland et al. (2018b) auf, die in ihrer Video-basierten Evaluierungsstudie ein κ von 0,88 ermittelten. Der grafische Vergleich von SB und HOBO nach dem von Bland und Altman (1986) empfohlenen Verfahren, ergab eine durchschnittliche Unterschätzung der auf Stunden-basis ermittelten Liegezeiten um 10 Minuten. Bezogen auf einen Tag, werden die Liegezeiten pro Kalb daher um ca. 240 Minuten unterschätzt. Aus praktischer und veterinärmedizinischer Sicht ist dieser Unterschied relevant und zur Beurteilung des Tierverhaltens nicht zu vernachlässigen. Die Übereinstimmung zwischen den beiden Messwertvarianten des HOBO-Loggers, d.h. zwischen Beschleunigungswert und Neigungswinkel, zeigte eine "fast perfekte Übereinstimmung" (Landis und Koch 1977). Die von Ledgerwood et al. (2010) getätigte Aussage, dass die Verwendung der beiden Parameter zur Beurteilung des Liegeverhaltens "im Ermessen des Benutzers" liegt, konnte in der vorliegenden Studie bestätigt werden. Darüber hinaus zeigten die Videoanalysen von 120 zufällig ausgewählten Videosequenzen mit "schnellem Wechsel" der Körperposition (d. h. Steh- und Liegeperioden von weniger als 3 Minuten während einer längeren Steh- oder

Liegeperiode) eine hohe Effizienz des von Ledgerwood et al. (2010) vorgeschlagenen Korrektur-Algorithmus zur Eliminierung fehlerhafter Datensequenzen in den HOBO- und SB-Datensätzen. Die Anwendung des zuvor genannten Algorithmus führte zu einer verbesserten Datenqualität und wird daher empfohlen.

Unter Berücksichtigung der zuvor genannten Studienergebnisse, ist das SB-System, unter Verwendung des für Kühe entwickelten Algorithmus, nicht in der Lage zuverlässige Informationen über das Liegeverhalten von Kälbern in Echtzeit zu liefern. Sofern der Einsatz des SB-Systems in der Praxis bzw. für Forschungsfragestellungen bei Kälbern geplant ist, sollten vorab speziell auf Kälber abgestimmte Algorithmen entwickelt und unter praktischen Bedingungen getestet werden.

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9 List of Tables

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