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Technical note: Evaluation of data loggers for measuring lying behavior in dairy calves

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ABSTRACT

Lying behavior might indicate how the animal interacts with its environment and is an important indicator of cow and calf comfort. Measuring behavior can be time consuming; therefore, behavioral recording with the help of loggers has become common. Recently, the Hobo Pendant G data logger (Onset Computer Corp., Bourne, MA) was validated for measuring lying behavior in cows but no work to date has validated this logger for measuring lying behavior in calves. The objective of this study was to test the accuracy of the Hobo Pendant G data logger for measuring total lying time and frequency of lying bouts in dairy calves. In 2 experiments (experiment 1: thirty-seven 2-h observation periods; experiment 2: nineteen 24-h observation periods), we tested the effect of 2 different recording intervals, the effect of attachment to different legs, and the effect of removing short, potentially erroneous readings. We found an excellent relationship when comparing the 30-s and 60-s recording intervals. For total lying time and bout frequency, the highest correlation was found when the logger was attached to the hind legs and recording was conducted with a 60-s sampling interval. In experiment 2, average total lying time was 1,077 ± 54 min/24 h (18.0 ± 0.9 h/24 h), with an average frequency of 19.4 ± 4.5 bouts per day. Predictability, sensitivity, and specificity for experiment 2 were >97% using the 60-s recording interval and removing single readings of lying or standing from the data set compared with direct observation as reference. The data logger accurately measured total lying time and bout frequency when the sampling interval was ≤60s and short readings of lying and standing up to 1 min were converted into the preceding behavior. The best results were achieved by attaching the logger to the right hind leg.
Key words: lying behavior, validation, calf, automated measurement

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Technical Note

Sufficient resting and sleeping time is particularly important for growing animals, and a relationship exists between lying time and age (Hänninen et al., 2005). Calves at the age of 2 wk spend 50 to 70% of the day lying down, and this time decreases to 37% of the day when the calves are 14 wk old (Webster et al., 1985; Chua et al., 2002; Hänninen et al., 2005). Adult cows spend between 5.2 (22%) and 16 h (67%) of the day lying down (Haley et al., 2000; Ledgerwood et al., 2010). In addition to age, lying behavior can be affected by several other factors, such as the housing system, flooring, or the presence or absence of social partners (Le Neindre, 1993; Bokkers and Koene, 2001; Phillips, 2004). Furthermore, pen size can affect the duration of locomotion and lying time (Bokkers and Koene, 2001; Rushen et al., 2007). Several studies report an association between lying time and flooring systems, such as depth and type of bedding in cows and calves (Haley et al., 2001; Tucker and Weary, 2004; Yanar et al., 2010). Recently, it was demonstrated in dairy cows that dry bedding (86.4 ± 2.1% DM) increased lying time by about 5 h/d compared with wet bedding (26.5 ± 2.1% DM; Fregonesi et al., 2007).

In addition to total lying time, the number of lying bouts, average bout duration, and laterality are part of the complex lying behavior (Tucker et al., 2009; Ledgerwood et al., 2010). These criteria might indicate how the animal interacts with its environment and are important indicators of cow comfort (Haley et al., 2000; Fregonesi and Leaver, 2001). Furthermore, lying behavior changes in diseased calves (Hart, 1988; Johnson, 2002). Calves spent more time lying inactive after a low dose injection of *Escherichia coli* endotoxin (0.025 µg of LPS/kg of BW; Borderas et al., 2008). In that study, the number and duration of bouts standing inactive decreased, whereas the total lying time did not change. In pigs, however, total lying time increased after an injection of 0.5 µg of LPS/kg of BW (Johnson and von Borell, 1994). Therefore, lying behavior might be a useful automatically measurable parameter for the detection of sickness.

Lying behavior has recently been studied by video or direct observation (Webster et al., 1985; Hänninen et al., 2005; Mattachini et al., 2011). This approach, however, is time consuming. A recent study showed that accelerometer data loggers such as the Hobo Pendant G Acceleration data logger (Onset Computer Corporation, Bourne, MA) attached to one leg are suitable for accurately recording lying behavior of dairy cows (Ledgerwood et al., 2010). In unweaned dairy calves, however, such accelerometers have not yet been validated. Therefore, the overall objective of this study was to validate a commercially available data logger for recording lying behavior of unweaned calves. Specifically, the objectives were (1) to compare the results considering different legs for attaching the logger, (2) to verify 2 sampling intervals, and (3) to quantify the effect of removing potential artifacts from the raw data sets.

Two experiments were conducted between March and October 2010 at the Clinic of Animal Reproduction, Freie Universität Berlin, Germany (experiment 1) and on a commercial dairy farm located in Saxony-Anhalt, Germany (experiment 2).

For recording the lying behavior of calves, electronic data loggers (Hobo Pendant G Acceleration Data Logger, Onset Computer Corp.) were used, as previously described in detail for dairy cows (Ito et al., 2009). In brief, data loggers were set to record the *g*-force and tilt of the x-, y-, and z-axes at 30-s or 60-s intervals. The loggers were wrapped in a 25- × 10-cm piece of gauze bandage to provide cushioning and were attached to the medial or lateral side of the leg above the metatarsophalangeal or metacarpophalangeal joint by using Vet Wrap bandage (Co-Flex, Andover Healthcare, Salisbury, MA).

In experiment 1 (March to April 2010), 8 calves (4 male, 4 female) at the age of 21.5 ± 14.5 d were observed for 2-h intervals. In total, thirty-seven 2-h observation periods were conducted. Four calves were kept in single pens of 2.5 × 1.4 m with visual contact with another calf (27 × 2-h observations), and 4 calves were housed in a group pen (4.0 × 2.5 m) with 1 other calf (10 × 2-h observations). Straw was used as bedding and all calves had ad libitum access to hay and water. Calves were observed for 4 ± 2 observation periods that each lasted 2 h. Each calf was fitted with 3 data loggers (i.e., medial side of the right hind leg, lateral side of the left hind leg, lateral side of the left front leg) for 4 ± 1d. Visual observation started 1 d after the data loggers had been attached. All direct observation periods were conducted by the same investigator between 0900 and 1500 h. When a lying bout of a calf lasted longer than 20 min, the calf was driven up to generate more lying and standing bouts.

Experiment 2 was conducted in October 2010 and used 19 female calves (29.4 ± 4.6 d) equipped with a data logger on the medial side of the right hind leg. The recording interval was set to 60 s for a 24-h recording period. All calves were housed in a straw-bedded freestall (10 × 4 m) in a group of 25 calves. Calves were fed 6 L of milk replacer (22.0% CP, 1.9% Lys, 0.6% Met, 19.0% crude fat, 0.1% crude fiber, 7.0% crude ash, 0.9% Ca, 0.7% P; Trouw Nutrition Deutschland GmbH, Burgheim, Germany) from an automatic feeder and had free access to hay, water, and a calf starter mixed on farm out of Ibeka Ideal 40 (20.0% CP, 3.8% crude fat, 6.0% crude fiber, 1.5% Ca, 0.7% P, 0.3% Na; HL Hamburger Leistungsfutter GmbH, Hamburg, Germany) and Milki Vitello (15.0% CP, 3.0% crude fat, 10.2% crude fiber, 5.5% crude ash, 0.8% Ca, 0.4% P, 0.3% Na; Trouw Nutrition Deutschland GmbH). A digital camera (Pentax Optio WS80; Pentax, Hamburg, Germany) with an 8 GB memory card (Entryx SD HC, Entryx, Hannover, Germany) was used for visual observations. The camera was secured on a beam 4 m above the ground and took a picture every 60 s to create 1,440 scan samples/24 h for each calf. Calves were marked with spray color for easy identification.

The data were downloaded using the Onset Hoboware Pro Software, exported into Excel (Microsoft Corp., Munich, Germany), and edited utilizing several macros (Ito et al., 2009). First, the degree of vertical tilt (y-axis) was used to determine the lying position of the animal, such that readings $<60°$ indicated the calf standing, and readings $\geq 60°$ indicated the calf lying down. Second, data were edited with 1 of 2 event filters to examine the effect of short, potentially erroneous readings of lying or standing events (Ledgerwood et al., 2010). These filter macros converted readings ≤ 1 min (i.e., the 1-min event filter) or ≤ 2 min (i.e., the 2-min event filter) to the behavior that preceded them. To imitate the 60-s recording interval in experiment 1, we removed every second measurement from the 30-s interval data before running the event filters. Finally, bout frequency and total lying time per observation period were calculated based on thirty-seven 2-h and nineteen 24-h observation periods in experiments 1 and 2, respectively.

Data were analyzed using SPSS for Windows (version 19.0, SPSS Inc., Munich, Germany) and MedCalc (version 12.0.3.0, MedCalc Software, Mariakerke, Belgium).

The relationship between total lying time and bout frequency measured by the logger and from direct observation were assessed using Pearson correlation coefficient (r). Coefficients of correlation were calculated to compare the 30-s and 60-s sampling intervals for the unfiltered data, 1-min event filtered data, and the

Table 1. Coefficients of correlation of lying behavior calculated with the Hobo Pendant G data logger (Onset Computer Corp., Bourne, MA) between 30-s and 60-s sampling intervals for thirty-seven 2-h observation periods from 8 calves (21.5 ± 14.5 d; experiment 1)

Parameter[1]	Unfiltered	1-min event filter[2]	2-min event filter[3]
Total lying time			
HR30s–HR60s	0.99***	0.99***	0.98***
HL30s–HL60s	0.97***	0.97***	0.97***
FL30s–FL60s	0.99***	0.96***	0.99***
Lying bouts			
HR30s–HR60s	0.83***	0.84***	0.91***
HL30s–HL60s	0.90***	0.87***	0.93***
FL30s–FL60s	0.68***	0.89***	0.94***

[1]HR30s = right hind leg, 30-s sampling interval; HL60s = left hind leg, 60-s sampling interval; FL30s = left front leg, 30-s sampling interval.

[2]Events ≤1 min were converted to the preceding behavior.

[3]Events ≤2 min were converted to the preceding behavior.

***$P < 0.001$.

2-min event filtered data of each leg. In experiment 1, we found an excellent correlation when comparing the 30-s and 60-s recording intervals for the thirty-seven 2-h observation periods (Table 1).

Furthermore, we observed strong correlations between lying times obtained from direct observation and those recorded by the loggers of all 3 legs ($P < 0.001$; Table 2). Coefficients of correlation for total lying time recorded on the hind legs were greater for the 60-s recording interval (r = 0.93 to 0.99, $P < 0.001$) than for the 30-s recording interval (r = 0.92 to 0.97, $P < 0.001$). Pearson correlation coefficient for total lying time was higher for the hind legs (r = 0.92 to 0.99, $P < 0.001$) than for the front leg (r = 0.89 to 0.92, $P < 0.001$). The highest correlation for total lying time was found when the logger was attached to the right hind leg and recording was conducted with a 60-s sampling interval (r = 0.99, $P < 0.001$).

For bout frequency, the hind legs (r = 0.62 to 0.85, $P < 0.001$) showed a greater correlation than the front leg (r = 0.58 to 0.72, $P < 0.001$; front leg with the 30-s recording interval: r = 0.30, $P < 0.073$). Coefficients of correlation for bout frequency were greatest between values from direct observation and data logger recordings for the unfiltered 60-s sampling interval of the left hind leg (r = 0.85, $P < 0.001$). For the filtered logger data, a sampling interval of 30 s was slightly better. But even with the 60-s recording interval and the 1-min event filter, the correlations between right hind leg and direct observation and left hind leg and direct observation were 0.76 ($P < 0.001$) and 0.77 ($P < 0.001$), respectively. The results of experiment 1 indicated that a sampling interval of 60 s is accurate.

Coefficient of correlation between total lying time measured with the data logger and by direct observation was r = 0.99. Total lying time obtained from the pho-

Table 2. Coefficients of correlation between lying behavior calculated with the Hobo Pendant G data logger (Onset Computer Corp., Bourne, MA) and direct observation for thirty-seven 2-h observation periods from 8 calves (21.5 ± 14.5 d) considering right and left hind legs and left front leg (experiment 1)[1]

	Unfiltered		1-min event filter[2]		2-min event filter[3]	
Parameter	60 s	30 s	60 s	30 s	60 s	30 s
Total lying time						
Obs–HR	0.99***	0.97***	0.98***	0.97***	0.98***	0.96***
Obs–HL	0.93***	0.92***	0.93***	0.92***	0.94***	0.92***
Obs–FL	0.92***	0.90***	0.89***	0.90***	0.92***	0.90***
Lying bouts						
Obs–HR	0.78***	0.65***	0.76***	0.85***	0.66***	0.75***
Obs–HL	0.85***	0.79***	0.77***	0.80***	0.62***	0.72***
Obs–FL	0.72***	0.30	0.66***	0.69***	0.58***	0.64***

[1]Obs = data from the direct observation; HR = right hind leg; HL = left hind leg; FL = left front leg; 60 s = logger sampling interval of 60 s; 30 s = logger sampling interval of 30s.

[2]Events ≤1 min were converted to the preceding behavior.

[3]Events ≤2 min were converted to the preceding behavior.

***$P < 0.001$.

tographic images of calves in experiment 2 was 1,078.3 ± 54.0 min (17.97 ± 0.9 h) per day, with an average frequency of 19.4 ± 4.5 bouts. The greatest correlation between the logger recordings and the photographic images for total lying time and bout frequency was found when removing single lying and standing events (r = 0.99, $P < 0.001$; r = 0.99, $P < 0.001$).

Because comparison of scaled variables using coefficients of correlation can be inappropriate, the agreement between the estimates of the logger and the photographic images in experiment 2 was graphically analyzed using the method described by Bland and Altman (1986). This method involves plotting the mean of the 2 measurements (i.e., visual observations and data loggers) against their difference. The agreement between the paired observations for total lying time and bout frequency is demonstrated in Figure 1. For total lying time, the mean difference was 0.0 ± 3.1 min, with lower and upper limit of agreements of −6.0 to 6.0 min when using the 1-min event filter. Only 1 observation (5.3%) was outside the 1.96 SD (Figure 1). The mean difference of 0.0 illustrated that the total lying time measured by the data loggers was almost identical to the values determined by visual observation when removing single lying and standing events (i.e., using the 1-min event filter method). For the data without an event filter or with the 2-min event filter, the mean differences were −2.4, and 0.4 min, respectively. For bout frequency, the mean difference was 0.68 ± 0.75 bouts with a lower and upper limit of agreement of −0.78 to 2.15 when using the 1-min event filter, and no observation (0.0%) was outside the 1.96 SD. Standard deviations and mean differences for total lying time and bout frequency were greater when using no event filter or the 2-min event filter.

In experiment 2, predictability (likelihood that a lying event recorded by the data logger was also recorded by the camera), sensitivity (likelihood that a lying event recorded by the camera was also recorded by the data logger), and specificity (likelihood that a non-lying event was recorded by both the data logger and the camera) for lying behavior were 99.3, 99.2, and 97.7%, respectively, for the 1-min event filter. All parameters were slightly lower when using no event filter (99.2, 99.3, and 97.1%, respectively) or the 2-min event filter (99.2, 99.2, and 97.6%, respectively). As an example, events recorded by the loggers (60-s interval, 1-min event filter) and from photographic images are summarized in Table 3. The average and maximum disagreements were 16 (1.1%) and 29 (2.0%) false readings. The logger monitoring system provided estimates of total lying time (1,078.3 ± 55.3 min) that were almost identical to those from direct observation (1,078.3 ± 54.0 min) considering an observation period of 1,440 min (24 h).

The data logger accurately measured lying time and bout frequency of calves. From these values, other parameters (e.g., average bout duration, longest and shortest bout) can be calculated. The sampling interval and editing method, however, influenced the accuracy of the information generated by the logger. In addition, the results obtained from loggers on the hind legs were more accurate than the results from front leg loggers, and even between the hind legs a slight difference was observed. This might be due to the greater flexibility of the front legs compared with the hind legs. More frequent and motile movements of the front leg might induce false readings. Furthermore, we speculate that the different position of the logger (lateral vs. medial) caused the variation between the hind legs. The lateral position of the logger on the left hind leg makes lying down on the left side uncomfortable, which provokes more leg movement and creates false readings.

In experiment 2, the calves were lying down 71 to 79% of the day. This is in the upper range compared with earlier studies (Warnick et al., 1977; Chua et al., 2002; Hänninen et al., 2005) and higher than reported by other authors (Le Neindre, 1993; Phillips, 2004; Yanar et al., 2010). This may be due to different recording methods and sampling intervals, as well as age and group size, bedding, and housing system. As expected, the calves in our experiment lay down longer than adult cows (Haley et al., 2001; Fregonesi et al., 2007; Ledgerwood et al., 2010). Coefficients of correlation and determination for lying time and bout frequency, respectively, were slightly higher in experiment 2 (r = 0.99, $P < 0.001$; r = 0.99, $P < 0.001$) than in experiment 1 (r = 0.98, $P < 0.001$; r = 0.76, $P < 0.001$), most likely because of the 2 different methods of direct observation. In experiment 1, the observer recorded lying behavior every 1 s and the logger had a sampling interval of 30 s, whereas in experiment 2, the photographic images, as well as the logger recordings, were snapshots of the behavior every 60 s. Therefore, the sampling intervals of the logger and direct observation were identical in experiment 2. Laterality could not be analyzed because the logger rotated around the leg in some calves. This is most likely due to the smaller diameter and the rounder shape of the calf leg compared with the cow leg, on which the logger is attached to an almost plane area. The bandage, however, could not be wrapped more tightly around the leg because of the potential for swelling. To avoid animal welfare issues (i.e., pain, discomfort), we compromised in the attachment of the loggers to prevent swelling and abandoned the laterality parameter.

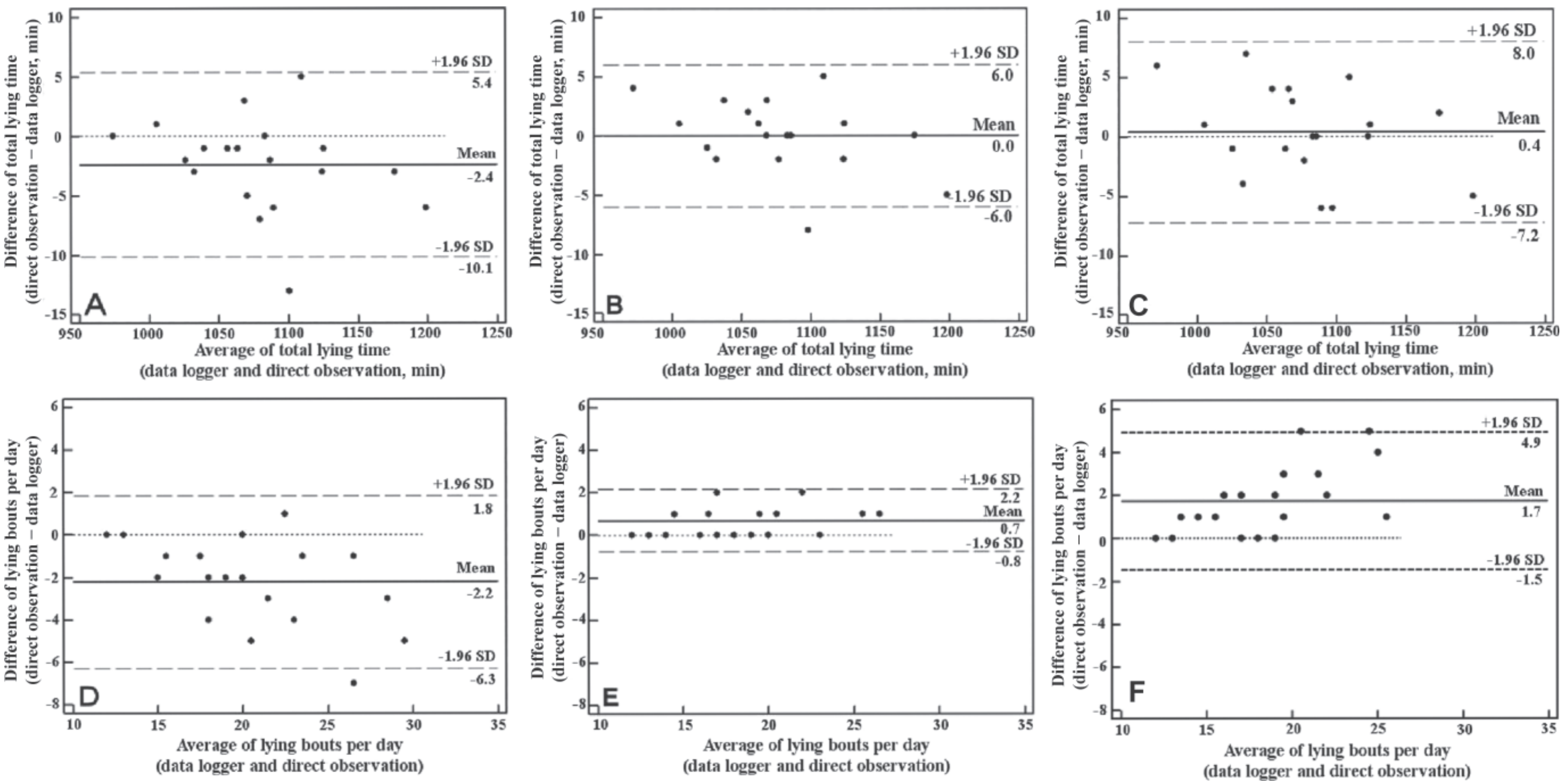

Figure 1. Bland-Altman plots comparing total daily lying time (A, B, C) and lying bout frequency (D, E, F) measured with the Hobo Pendant G data logger (Onset Computer Corp., Bourne, MA) set to record at 60-s intervals and direct observation for no event filter (A, D), 1-min event filter (B, E), and 2-min event filter (C, F). Data are shown for 19 calves (29.4 ± 4.6 d) from experiment 2.

Table 3. Lying and standing events (number of events) recorded with the Hobo Pendant G data logger (Onset Computer Corp., Bourne, MA) set to record at 60-s intervals and filtered with a macro that converted single readings of lying and standing to the behavior that preceded them and photographic images taken every minute from 19 calves (29.4 ± 4.6 d) for 24 h (experiment 2)

Calf	Camera = lying Logger = lying[1]	Camera = lying Logger = standing[2]	Camera = standing Logger = lying[3]	Camera = standing Logger = standing[4]	False readings[5]
1	1,078	7	7	348	14
2	1,110	12	14	304	26
3	1,075	7	7	351	14
4	1,166	8	8	258	16
5	1,098	13	8	321	21
6	1,055	7	6	372	13
7	1,060	8	7	365	15
8	967	8	2	463	10
9	1,190	6	10	234	16
10	1,061	9	5	365	14
11	1,088	6	13	333	19
12	1,071	15	14	340	29
13	1,000	6	4	430	10
14	1,027	11	8	394	19
15	1,048	7	5	380	12
16	1,116	8	7	309	15
17	1,070	5	7	358	12
18	1,025	5	7	403	12
19	1,017	7	8	408	15

[1]Recordings (no.) when both the data loggers and the camera detected a lying event.

[2]Recordings (no.) when only the camera detected a lying event.

[3]Recordings (no.) when only the data loggers detected a lying event.

[4]Recordings (no.) when neither the data loggers nor the camera detected a lying event (i.e., standing).

[5]Recordings (no.) when the logger detected a different event than the camera.

The Hobo Pendant G data logger was recently validated for use in cows (Ledgerwood et al., 2010); however, to our knowledge this is the first study to investigate the use of this logger to record lying behavior in young calves. The data logger accurately measured total lying time and bout frequency when the sampling interval was ≤60 s and short readings of lying and standing up to 1 min were converted into the preceding behavior. We recommend attaching the logger to the left or right hind leg of calves. Further research is needed to determine normal lying behavior in calves considering different housing and management systems.

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