Author(s): Nina Pirinen, Matti Pastell, Anna Mykkänen, Catherine McGowan and Heli Hyytiäinen

Title: Validation of a tail-mounted triaxial accelerometer for measuring foals' lying and motor behavior

Year: 2020

Version: Published version

Please cite the original version:

Pirinen N., Pastell M., Mykkänen A., McGowan C., Hyytiäinen H. (2020). Validation of a tail-mounted triaxial accelerometer for measuring foals' lying and motor behavior,Journal of Veterinary Behavior 39: 14-20. https://doi.org/10.1016/j.jveb.2020.06.004.

Journal of Veterinary Behavior 39 (2020) 14–20

Contents lists available at ScienceDirect

Journal of Veterinary Behavior

journal homepage: www.journalvetbehavior.com

Research

Validation of a tail-mounted triaxial accelerometer for measuring foals' lying and motor behavior

Check for updates

Nina Pirinen [a,*], Matti Pastell [b], Anna Mykkänen [a], Catherine McGowan [c], Heli Hyytiäinen [a]

[a] Department of Equine and Small Animal Medicine, Faculty of Veterinary Medicine, University of Helsinki, Helsinki, Finland
[b] Natural Resources Institute of Finland (Luke), Production Systems, Helsinki, Finland
[c] School of Veterinary Science, Faculty of Health and Life Sciences, University of Liverpool, Liverpool, UK

ARTICLE INFO

Article history:
Received 28 March 2020
Received in revised form
23 May 2020
Accepted 25 June 2020
Available online 30 June 2020

Keywords:
equine
horse
locomotion
gait analysis
motor development
accelerometer

ABSTRACT

Foals' locomotory and lying-down behavior can be an indicator of their health and development. However, measurement tools have not been well described with previously reported attachment sites used on limbs of adult horses unsafe for longer-term data collection in foals. In this study, a tail-mounted three-dimensional accelerometer was validated for monitoring foals lying, standing, and walking behavior. Eleven foals were recruited: four hospitalized and seven at private breeding stables. Accelerometers were attached to the dorsal aspect of the base of each foal's tail and their behavior was video recorded. Hospitalized foals had continuous video monitoring inside their stalls, and the breeding stable's foals were monitored outside at pasture for 1-5 periods (mean 42 minutes per period), depending how long they were at the facility. Acceleration was measured using 100 Hz frequency and mean, maximum, and minimum acceleration were recorded in 5 second epochs for x-, y-, and z-axes. Lying, standing, and walking behavior was monitored from videos of all foals, and the start and end time of each behavior was compared with the corresponding data from the accelerometer. Naive Bayes classifier was developed by using dynamic body acceleration and craniocaudal movement of the tail (tilt along z-axis), to predict a foal's lying behavior.

The model was validated; the classifier achieved high accuracy in precision and in classifying foals' lying behavior (specificity, 0.92; sensitivity, 0.89; precision, 0.98; accuracy, 0.92). The overall accuracy for classifying walking and standing was also good, but the precision was poor (0.46 and 0.24, respectively). When standing and walking behavior was combined to a single "standing or walking" class, the precision improved (specificity, 0.62; sensitivity, 0.92; precision, 0.89; accuracy, 0.92). In conclusion, tail-mounted three-dimensional accelerometer can be used for monitoring foals' lying behavior. In addition, information regarding standing and walking can be gained with this method.

Introduction

Foals have evolved to be well adapted to early locomotion which plays an important part of their growth and development (Barneveld and van Weeren, 1999; Kurvers et al., 2006). Foals' physical activity, found in previous studies to be highest during the first month of life, is important for growth-related development of musculoskeletal system (Kurvers et al., 2006). Lack of exercise can cause delays in tissue development and has been shown to influence bone density and chemical composition of tendons and articular cartilage (Back et al., 1999; Barneveld and Weeren, 1999; Kurvers et al., 2006). Restricted exercise also affects foals' gait patterns. Foals kept box-rested for the first 5 months of life had hypermetric gait patterns and poorer coordination than foals that were able to move freely in paddocks with their mothers (Back et al. 1999; Barneveld and van Weeren 1999; Kurvers et al., 2006). In addition to moving, rest is also important—not only for growing foals, but also for animal welfare in all stages of life. Alterations to rest periods can be an indicator of welfare or health problems

* Address for reprint requests and correspondence: Nina Pirinen, Department of Equine and Small Animal Medicine, Faculty of Veterinary Medicine, Viikintie 49, P.O. Box 57, Helsinki 00014, Finland. Tel: +358 400850418; Fax: +3582941 57281.
E-mail address: nina.pirinen@helsinki.fi (N. Pirinen).

https://doi.org/10.1016/j.jveb.2020.06.004

(Borderas et al. 2008; Chen et al., 2017). Increased lying time can be an early sign of illness, thus any changes on the lying behavior needs to be monitored carefully. Accelerometers could offer a tool for continuous monitoring of foals' locomotion.

Motor behavior can be monitored with direct and with video-recording observations. During short periods, video recording is a good way to monitor activity, but if the observation period is long, data analysis can be time-consuming. In addition to video, automated recording devices have been developed and used to decrease the workload in assessing motor behavior (Champion et al., 1997; Trenel et al., 2009; Ledgerwood et al., 2010; DuBois et al., 2015). Three-dimensional accelerometers (3DAs) have been shown to be suitable for recording motor behavior in cows and in adult horses (Ledgerwood et al., 2010; Bonk et al., 2013; DuBois et al., 2015). A recently published study by Murase et al. (2018) used 3DAs to monitor Thoroughbred foals' lying behavior: frequency and bouts were monitored under different environmental conditions. The foals were found to lie down longer, and more in lateral recumbency, in stables than on pasture.

In comparison with neck- or body-mounted devices (Champion et al., 1997; Martiskainen et al,. 2009; Vázquez Diosdado et al., 2015), leg-mounted ones have appeared to be more accurate for monitoring dairy cattle movements (Trenel et al., 2009; Ledgerwood et al., 2010; Alsaood et al., 2015). In a study by DuBois et al. (2015) with adult horses, the accelerometers were attached to a hind limb for a 5-day period during constant supervision. In a foal study, accelerometers were attached on the side of the hind limb cannon bone and under the halter, and data were recorded for two consecutive 24-hour periods each week until weaning (Murase et al., 2018). With actively moving foals, leg-mounted devices may not be safe for continuous long-term recording, which may be beneficial for abnormal behavior detection or to ensure sufficient data collection for research purposes. Curious and agile foals can easily get halter or leg-mounted devices trapped in fencing or other objects if they are kept on for longer periods without surveillance. The tail, instead, might provide a safe placement for the device. However, according to our knowledge, foal's tail has not been previously used as an attachment site for accelerometers.

The aim of this study was to validate the use of a 3DA attached to a foal's tail as a method of measuring the foal's lying and locomotory behavior. Our first hypothesis was that an accelerometer attached to a foal's tail is a valid method for measuring its lying behavior. The second hypothesis was that other behaviors, including standing and walking, can also be determined with tail-attached accelerometers.

Materials and methods

The study received approval from University of Helsinki, Viikki Campus Research Ethics Committee. Signed consent from the foals' owners was also received.

Animals

Owners of foals admitted to the University of Helsinki Veterinary Teaching Hospital and Evidensia Equine Hospital Hyvinkää from April to August in 2016 were asked to participate in the study (hospitalized foals, HF). In addition, all owners of the foals at a private breeding stable were asked to participate in the study from April to August 2016 and 2017 (breeding stable foals, BSF).

Eleven foals, four HF and seven in BSF, participated in the study. Of the HF, three were from Helsinki University Teaching Hospital and one from Evidensia Equine Hospital Hyvinkää. The reasons for admittance to the hospitals were perinatal asphyxia syndrome (n = 1), sepsis (n = 1), and meconium impaction (n = 2). Two of the HF were colts (n = 2) and two fillies (n = 2), three Standardbreds (n = 3), and one Finnhorse (n = 1). One of the foals was 2 days old on arrival (n = 1), the other three were 1 day old (n = 3). The HF were monitored the whole hospitalization time. Mean in-patient time was 5 days, ranging 2-10 days.

From the BSF, there was one Finnhorse (n = 1), four Finnish warmbloods (n = 4), one Hannover (n = 1), and one Rhenish warmblood (n = 1). One was a filly (n = 1) and the other six were colts (n = 6). The foals were healthy and monitored outside at the breeding stable for a mean of 2.86 times (range 1-5 times), with mean recording time of 42 min per recording (range 7-65 min). The BSF stayed at the breeding stable for a mean of 16 days (range 2-30 days).

Accelerometer and cameras

Acceleration was measured using a MEMS (micromachined microelectromechanical systems)-type 3DA (Vibration Sentry E-16g, Convergence Instrument, Canada, dimensions 7.62 × 3.94 × 2.06 cm) (Figure 1). The device was chosen because of its high memory capacity, which would make it suitable for long-term observations. The accelerometer was attached by one of the authors, an experienced veterinarian (NP), to the foal's tail using Leucoplast© tape to hold it in place (Figure 2). When the device was attached for the first time, the foal's behavior was monitored carefully to see if the foals or mares reacted to the device. Increased tail movements, looking at the tail direction, kicking, biting, or nervous behavior could have been a sign of discomfort for the foal. In cases of signs of discomfort, the device would have to be removed. The mares were also monitored, as they could potentially try to remove or bite the device. If the mares showed interest in the device (smelling, touching, repeatedly looking at the device or tail area), it would have to be removed to avoid possible violent

Figure 1. Accelerometer used in the study: Vibration Sentry E-16g; Convergence Instrument, Canada.

Figure 2. Accelerometer attached to a foal's tail using Leucoplast© tape to hold it in place.

removal of it by the mare. To prevent skin damage, accelerometers were attached to the hair of the tail and they were rechecked every 24 h during the whole in-hospital period with the HF. In the BSF, accelerometers were in place only during their shorter monitoring period and no extra recheck was needed. The 3DAs were positioned with positive z-axis pointing cranially, positive x-axis laterally, and positive y-axis vertically. The logger measured acceleration using ±16g measurement range with 100 Hz sampling frequency and recorded mean, maximum, and minimum acceleration of each axis in device memory in 5 second epochs based on pilot measurements (Pirinen et al., 2016) and sampling rate used in previous accelerometer studies (Hokkanen et al. 2011; Thompson et al., 2015). Continuous video recordings (MS-C2163-PN; Milesight, of 20 frames/second, USA) were used with the HF, as well as with the BSF (SJAM 1080P HD, of 30 frames/second, China). Cameras were attached to the wall of the stable of the HF, so that the foals were fully visible. With the BSF, the camera was hand-held or attached to the fence of the pasture for the whole monitoring time, such that in both cases the pasture was fully visible. The cameras and accelerometers were synchronized with a resolution of one second.

After the recordings, data were downloaded from accelerometers and cameras and saved to an external hard drive. The videos were analyzed retrospectively. Behavior as lying, standing, and walking was monitored from the videos. Walking behavior was defined as having the footfall pattern of walk with the center of mass moving forward. Standing, in turn, was defined as body positioned upright, all four feet bearing weight. Lying was defined as the flank and chest touching the ground. All three behaviors were timed when they had continued for more than 3 seconds. Lying was timed from when the flank and chest met the ground and ended when the foal started to get up and flank and chest were lifted from the ground. For each behavior of the HF, the start and end time of 50 occurrences was recorded. In case of less than 50 occurrences being available, all available occurrences were used. The number of occurrences was limited to 50 because of longer monitoring time of the HF. For the BSF, each behavior and all occurrences were recorded from the video and compared with the corresponding times from the accelerometer data.

Data collection

The HF participated in the study throughout their whole inpatient period. Accelerometers were attached at the dorsal aspect of the base of the foals' tail on arrival in hospital, and a constant video recording was started. The HF were monitored in the stables (stable size 4 m × 4 m). Monitoring time was dependent on the days the HF were treated in hospital, which ranged from 2 to 10 days.

The BSF were monitored 1-5 times at a pasture, at the breeding stable, where they were living with their dams (pasture size 30 m × 30 m). With the BSF, the monitoring period was dependent on the length of their stay at the breeding facility during the first month of their life. Monitoring days were prescheduled with stable keeper. On those days, the accelerometers were attached to the foals before turning the foals out to the pasture, and they were video recorded constantly during the period they were out; total monitoring times per foal were 2.86 times (range 1-5 times) and the mean recording time was 42 min per recording (range 7-65 min).

Calculating features from accelerometer data

Accelerometers measure both static and dynamic acceleration. Static acceleration can be used to calculate the orientation of the sensor with respect to direction of gravity. We calculated the tilt angle from reference position between each axis and gravity vector using (Fisher, 2010):

$$\theta = \tan^{-1}\frac{x_{avg}^2}{\sqrt{y_{avg}^2 + z_{avg}^2}}$$

$$\psi = \tan^{-1}\frac{y_{avg}^2}{\sqrt{x_{avg}^2 + z_{avg}^2}}$$

$$\phi = \tan^{-1}\frac{\sqrt{x_{avg}^2 + y_{avg}^2}}{z_{avg}}$$

Dynamic acceleration describes the overall acceleration of the sensor without the static gravity component. We calculated dynamic body acceleration (DBA) of the sensor as

$$\text{DBA} = x_{range} + y_{range} + z_{range}$$

Table 1
Number of samples/class in training and validation data set

Data set	Lying	Standing	Walking
Training	24,739	4913	1662
Validation	37,736	4406	890

Naive Bayes classifier

We developed a naive Bayes classifier (NBC) to predict the behavior of a foal based on the measurement data. The NBC was chosen because the relationship between input variables and output classification is easy to interpret and the data set was relatively small, which can lead to problems with overfitting when using more complex classifiers.

The NBC assigns a sample to a new class C_k based on the probability that the measured sample represents that class (Barber 2012). The classification is performed based on class probabilities fitted for each feature and class on a training data set. In the NBC, the probability of a class given features is proportional to

$$p(C_k|\mathbf{x})) \propto p(C_k)p(\mathbf{x}|C_k)$$

where $\mathbf{x}$ is a feature vector $x_1, \ldots, x_n$ for each sample and $p(C_k)$ is the prior probability of the class. To simplify the calculation, naive Bayes assumes that features are conditionally independent:

$$p(C_k|x) \propto p(C_k) \prod_{i}^{N} p(x_i|C_k)$$

According to the decision rule, the sample is assigned to the class $\hat{C}_k$ with the highest posterior probability

$$\hat{C}_k = \text{argmax}(p(C_k|\mathbf{x}))$$

Fitting classifier model

To fit and validate NBC, we split the collected data into training and validation data sets by randomly selecting 4 (of 7) BSF and 2 (of 4) HF to be used for training that is fitting the NBC. The data from remaining foals were used for model validation. The split resulted in 31,314 samples in the training data set and 43,032 in the validation data set. The proportion of the classes is shown in Table 1.

We explored the most informative features (mean, minimum, maximum, range, tilt angles between all axes) for behavioral classification by fitting the NBC with all features calculated from the accelerometer data. Finally, we chose to use features DBA and ϕ (tilt along z-axis) which produced the best classification results on the training data set. To avoid class imbalance, we fitted normal distribution for ϕ and Weibull distribution for DBA separately to each class from the training data set. The goodness of fit for the distributions was inspected graphically. Owing to a large class imbalance and limited observations on expected prevalence of behavioral classes in the data set, we used equal prior probability $p(C_k)$ for each class, and omitted that term from the decision rule The predicted class was thus obtained using

$$\widehat{C}_k = \text{argmax}(p(C_k|\phi) \cdot p(C_k|DBA))$$

We evaluated the performance of the fitted NBC using the validation data set. The classifier was evaluated by calculating the accuracy (agreement between the observed and predicted classes), precision (positive predictive value), specificity (true negative rate), sensitivity (true positive rate) and, F1 score for each behavior (Kuhn & Johnson, 2013). The evaluation was carried out for each behavior separately and for combined model where standing and walking were combined to a single “Standing or Walking” class.

The model was implemented using the Julia language (Bezanson et al., 2017) version 1.1. The full source code and data used for model development are available from https://github.com/mpastell/foal-behavior-accelerometers.

Results

Video observation data

Videos were analyzed retrospectively and behaviors of lying, standing, and walking were monitored from videos. For each behavior of the HF, the start and end time of 50 occurrence was recorded. In the case of less than 50 occurrences being available, all available occurrences were used. With the HF, there were 188 walking, 564 standing, and 185 lying bouts during the 20 monitoring days. For the BSF, each behavior and all occurrences were recorded from video and there were 449 walking, 619 standing, and 34 lying bouts in 814 monitoring minutes during the recorded 13.5 hours. Times for each behavior were compared with the corresponding times from accelerometer data. This yielded a total of 637 walking, 1,183 standing, and 219 lying bouts, and 74,346 acceleration samples.

Accelerometer data

Figure 3 shows the kernel density estimates for ϕ and DBA from the whole data, and Figure 4 shows the fitted distributions on the

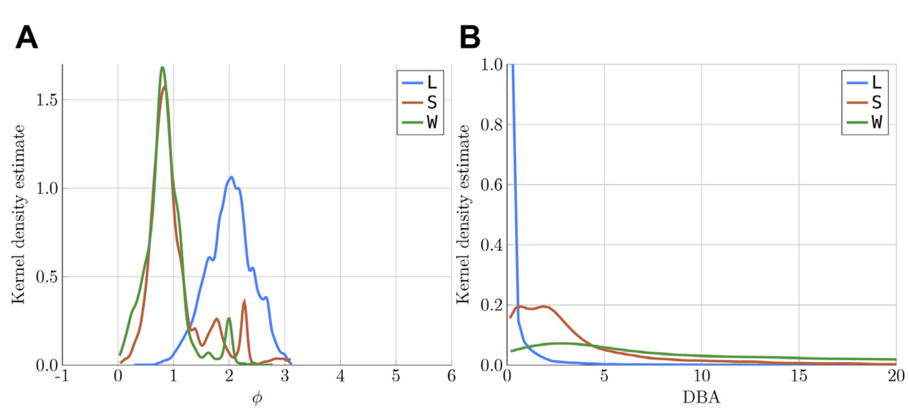

Figure 3. Kernel density estimates for ϕ (A) and dynamic body acceleration (DBA) (B) for each behavior. (A) Representing x accelerometers’ position in the tails (tilt along z-axis) and y kernel density for lying (blue; L), standing (red; S), and walking (green; W) behavior in 11 foals. (B) Representing x overall acceleration of the sensor, y kernel density for lying, standing, and walking behaviors in 11 foals. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

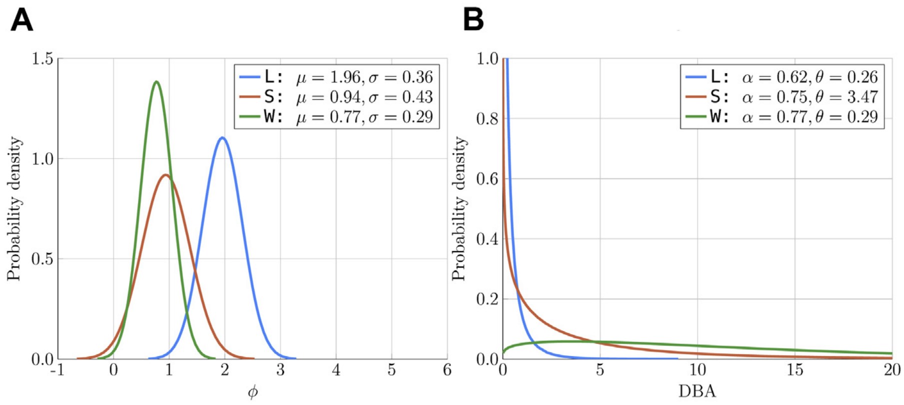

Figure 4. Fitted distributions for ϕ (A) and dynamic body acceleration (DBA) (B) for each behavior. (A) Representing x accelerometers' position in tails (tilt along z-axis) and y probability density for lying (blue; L), standing (red; S), and walking (green; W) in the training data set. (B) Representing x overall acceleration of the sensor, y probability density for lying, standing, and walking in the training data set. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

training data set for the same variables. The figures show that distributions of these features clearly differ for each behavioral class, but that there is also a lot of overlap between the categories.

The NBC achieved both good accuracy in precision in classifying when the foals were lying. The overall accuracy for classifying walking and standing was also good, but the precision was poor. When we combined the standing and walking to single "standing or walking" class, the precision was improved (Table 2).

Discussion

This study achieved its aim to validate tail-mounted 3DAs for measuring foals' lying behavior using an accelerometer attached to a foal's tail. In lying, the foals kept their tail more elevated and the values were more positive than with standing and walking. In standing and walking, the tail position was almost the same, more down following the angle of the sacral spine. The DBA was lower with lying behavior when the tail was more still and relaxed, and higher with standing and walking where tail movements were more frequent. We found that the NBC achieved high accuracy and precision in classifying the foal's lying behavior (specificity, 0.92; sensitivity, 0.89; precision, 0.98; accuracy, 0.92). In a previous study with adult horses, predictability, sensitivity, and specificity were over 99% for monitoring horses' lying behavior with accelerometers (DuBois et al. 2015). In that study, the device used, the calculation of the used model, and the parameters for calculating it were very different from ours, which makes it impossible to compare their methodology directly with ours. In previous studies, calculations were performed with raw acceleration (DuBois et al., 2015; Murase et al., 2018) which differs from our study, where we used acceleration features from 5 second bouts. However, it seems that the results are comparable and both methods are reliable for measuring resting behavior.

In addition to lying behavior, we hypothesized that other behaviors, that is standing and walking, could also be determined from DBA. When standing and walking was combined to "standing and walking" class, the precision and classification was moderate (specificity, 0.62; sensitivity, 0.92; precision, 0.89; accuracy, 0.92), but the overall precision for differentiating walking and standing was low (precision 0.46 and 0.24, respectively). The main reason for overlaps between standing and walking were most likely tail movements, which were seen on the videos. Even though most of the behaviors seen in young foals are not affected by tail movements (Crowell-Davis et al., 1987; Strasinger et al., 2013), the foals seem to move their tails regardless of what they were doing. Reasons for tail movements could be irritation caused by insects or the device; the foals also seemed to move their tail more just before they started to frolic. Mostly, movements were from side to side, but lifting the tail was seen during urination or defecating. During lying behavior, the tail was mostly still; only very few tail movements from side to side was seen when the behavior started, and they were most likely caused by irritation of insects.

The tail-mounted accelerometers may have caused some extra tail movements, although they appeared to be very well accepted and no signs of discomfort were seen on any of the foals, nor was adverse behavior by the mares noticed. Devices were easy to secure and maintain in place; being mounted while the foals were standing or lying and neither the foals nor mares paid attention to them. With the HF, the 3DA was needed to be checked and occasionally remounted because of longer monitoring time, but with the BSF, it stayed in place even though the foals moved faster outside despite the weather conditions. Only one among the BSF managed to remove the device during night time in the stable, which was not included in our monitoring time. With some HF, the tape that was used to mount the device cut few hairs from the tail, otherwise no skin lesions were seen. In a recently published study, the measurement device was attached to the cannon bone of the hind limb and under the halter (Murase et al., 2018). Our concern was that with longer monitoring time, the actively moving foals may get injured from the device. Moreover, there would be a risk of skin lesions and pressure injuries and getting the device trapped in solid objects. Longer monitoring time was needed to ensure sufficient amount of data for validation. It may be that this concern is unnecessary, as in the previous study they did not report any problems with attachment of device even though it was kept for several hours in the pasture and stable. Leg-mounted devices have also been used with adult horses (DuBois et al. 2015) and in previous studies with cattle without problems (Trenel et al. 2009; Ledgerwood et al. 2010).

Table 2
Naive Bayes classifier performance

Behavior	Accuracy	Precision	Specificity	Sensitivity	F1 Score
Lying	0.92	0.98	0.92	0.89	0.95
Standing	0.89	0.46	0.62	0.92	0.53
Walking	0.96	0.24	0.47	0.97	0.32
Standing or walking	0.92	0.89	0.62	0.98	0.73

Previously, standing and lying behavior has been monitored by measuring raw acceleration in adult horses every 20 seconds for period of 5 days, and with foals every 10 seconds for a period of 24 hours (DuBois et al., 2015; Murase et al., 2018). For identifying and classifying all locomotor behavior patterns including even faster movements such as trotting and galloping, the sampling rate with raw acceleration should be much higher, for example, previously reported 33 per second (de Passille et al., 2010). The main limitation for a higher sampling window is memory capacity and battery life of devices which prevents longer monitoring time. We decided to use calculated acceleration features to reduce memory load and enable long-term recording instead of collecting raw data. Our sensor measured acceleration at 100 Hz and recorded the features (mean, maximum, and minimum) of each axis in memory for the duration of log interval, which in this study was 5 seconds. The device we used (Vibration Sentry E-16g; Convergence Instrument, Canada) can record acceleration statistics continuously at 5-second intervals for 50 days.

The recording epoch of 5 seconds provided sufficient temporal resolution compared with duration of behavioral bouts and provided good results for discriminating between lying standing. However, the measurement of raw acceleration would have provided more information on the type of movement that occurred during the epochs. The main limitations of our method is that a single large peak (i.e., single tail slash while standing) and continuous movement causing several large peaks (i.e., walking), results in similar acceleration features in the stored 5-second window as only the mean, maximum, and minimum of the epoch were recorded. Getting more accurate features describing the foal motion, such as spectral features (Rahman et al., 2018), wavelet variance (Hokkanen et al., 2011), root mean square acceleration (Benaissa et al., 2019), or empirical cumulative distribution function (Thompson et al., 2016), would potentially be useful for differentiating between standing and walking or even faster movements. We also explored the possibility of using a support vector machine classifier instead of the final NBC achieving similar results. However, we decided to use the NBC as the final model because of interpretability of the class distributions.

Other limitations were small group size and different environmental conditions and health status between the HF and BSF, which could have influenced the results. Healthy BSF may have moved their tail more than sick HF, that is, while standing which may have caused overlap between standing and walking groups. Future research using larger study groups of healthy foals used at pasture and stabled with a higher log interval are warranted.

Conclusion

In conclusion, tail-mounted 3DA can be used for monitoring foals' lying behavior. In addition, information regarding standing and walking can be gained with this method. This tool can provide clinician as well as researchers a valid method for objective measurement of foals' motor behavior.

Acknowledgments

The authors would like to thank the owners of the foals for participating in the study. Moreover the authors would like to thank the whole personnel of University of Helsinki Equine Teaching Hospital and Evidensia Equine Hospital Hyvinkää. In addition, they thank Katja Lappalainen for her collaboration. Furthermore, acknowledgments are extended to Erkki Rajakoski Foundation, Orion Research Foundation, Finnish Foundation of Veterinary Research and Mercedes Zachariassen for their financial support.

Conflict of interest

The authors declare no conflict of interest.

Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jveb.2020.06.004.

References

Alsaaod, M., Niederhauser, J.J., Beer, G., Zehner, N., Schuepbach-Regula, G., Steiner, A., 2015. Developmentand validation of a novel pedometer algorithm to quantify extended characteristics of the locomotorbehavior of dairy cows. J. Dairy Sci. 98, 6236–6242.
Back, W., Smit, L.D., Schamhardt, H.C., Barneveld, A., 1999. The influence of different exercise regimens on the development of locomotion in the foal. Equine Vet. J. 31, 106–111.
Barber, D., 2012. Bayesian Reasoning and Machine Learning. Cambridge University Press, Cambridge, United Kingdom.
Barneveld, A., van Weeren, P.R., 1999. Conclusions regarding the influence of exercise on the development of the equine musculoskeletal system with special reference to osteochondrosis. Equine Vet. J. Supp. 31, 112–119.
Benaissa, S., Tuyttens, F.A.M., Plets, D., Cattrysse, H., Martens, L., Vandaele, L., Joseph, W., Sonck, B., 2019. Classification of ingestive-related cow behaviours using RumiWatch halter and neck-mounted accelerometers. Appl. Anim. Behav. Sci. 211, 9–16.
Bezanson, J., Edelman, A., Karpinski, S., Shah, V.B., 2017. Julia: a fresh approach to numerical computing. SIAM Rev. 59, 65–98.
Bonk, S., Burfeind, O., Suthar, V.S., Heuwieser, W., 2013. Technical note: Evaluation of data loggers for measuring lying behavior in dairy calves. J. Dairy Sci. 96, 3265–3271.
Borderas, T.F., de Passille ́, A.M., Rushen, J., 2008. Behaviour of dairy calves after low dose of bacterial endotoxin. J. Anim. Sci. 86, 2920–2927.
Champion, R.A., Rutter, S.M., Penning, P.D., 1997. An automatic system to monitor lying, standing and walking behaviour of grazing animals. Appl. Anim. Behav. Sci. 54, 291–305.
Chen, J.M., Stull, C.L., Ledgerwood, D.N., Tucker, C.B., 2017. Muddy conditions reduce hygiene and lying time in dairy cattle and increase time spent on concreto. J. Dairy Sci. 100, 2090–2103.
De passile, A.M., Jensen, A.M., Chapinal, N., Rushen, J., 2010. Technical note: use of accelerometers to describe gait patterns in dairy calves. J. Dairy Sci. 93, 3287–3293.
DuBois, C., Zakrajsek, E., Haley, D.B., Merkies, K., 2015. Validation of triaxial accelerometer to measure the lying behavior of adult domestic horses. Animal 9 (1), 110–114.
Crowell-Davis, S.L., Houpt, K.A., Kane, L., 1987. Play development in Welsh pony (Equus caballus) foals. Appl. Anim. Behav. Sci. 18 (2), 119–131.
Fisher, C.J., 2010. Using an Accelerometer for Inclination Sensing. AN-1057, Application Note. Analog Devices, Norwood, MA.
Hokkanen, A.-H., Hänninen, L., Tiusanen, J., Pastell, M., 2011. Predicting sleep and lying time of calves with a support vector machine classifier using accelerometer data. Appl. Anim. Behav. Sci. 134, 10–15.
Kuhn, M., Johnson, K., 2013. Applied Predictive Modeling. Springer, New York, NY, pp. 1–16.
Kurvers, C.M.H., van Weeren, R.P., Rogers, C.W., van Dierendonck, M.C., 2006. Quantification of spontaneous locomotion activity in foals kept in pastures under various management conditions. Am. J. Vet. Res. 67 (7), 1212–1217.
Ledgerwood, D.N., Winckler, C., Tucker, C.B., 2010. Evaluation of data loggers, sampling intervals, and editing techniques for measuring the lying behavior of dairy cattle. J. Dairy Sci. 93, 5129–5139.
Martiskainen, P., Järvinen, M., Skön, J.P., Tiirikainen, J., Kolehmainen, M., Mononen, J., 2009. Cow behaviour pattern recognition using three-dimensional accelerometer and support vector machines. Appl. Anim. Behav. Sci. 119, 32–38.
Murase, H., Matsui, A., Endo, Y., Sato, F., Hada, T., 2018. Changes of lying behaviour in Thoroughbred foals influenced by age, pasturing time, and weather conditions. J. Equine Sci. 29 (3), 61–66.
Pirinen, N., Pastell, M., Mykkänen, A., Jokisalo, J., Niinistö, K., Hänninen, L., McGowan, C., Hyytiäinen, 2016. Tail as an accelerometer attachment site when measuring foals'motor behaviour- a preliminaru study. Acta Vet. Scand. 58 (suppl 2), A24.
Rahman, A., Smith, D.V., Little, B., Ingham, A.B., Greenwood, P.L., Bishop-Hurley, G.J., 2018. Cattle behaviour classification from collar, halter, and ear tag sensors. Info. Proc. Agricult. 5, 124–133.
Strasinger, L.A., Fowler, A.L., Hayes, S., Lawrence, L.M., 2013. Foal behaviour during the early neonatal period. J. Equine Vet. Sci. 33 (5), 363.
Thompson, R., Kyriazakis, I., Holden, A., Olivier, P., Plötz, T., 2015. Dancing with horses: automated quality feedback for dressage riders. In: Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous

Computing, UbiComp ’15. Association for Computing Machinery, Osaka, Japan, pp. 325–336.
Thompson, R., Matheson, S.M., Plötz, T., Edwards, S.A., Kyriazakis, I., 2016. Porcine lie detectors: Automatic quantification of posture state and transitions in sows using inertial sensors. Comp. Electron. Agricult. 127, 521–530.
Trenel, P., Jensen, M.B., Decker, E.I., Skoth, F., 2009. Technical note: quantifying and characterizing behavior in dairy calves using IceTag automatic recording device. Dairy Sci. 92, 3397–3401.
Vázquez Diosdado, J.A., Barker, Z.E., Hodges, H.R., Amory, J.R., Croft, D.P., Darren, P., Bell, N.J., Codling, E.A., 2015. Classification of be-haviour in housed dairy cows using an accelerometer-based activity monitoring system. Anim. Bioteleme. Try. 3, 15.