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Short communication

Automated measurement of lying behavior for monitoring the comfort and welfare of lactating dairy cows

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ABSTRACT

Behavioral monitoring may be useful to assess the welfare, state of health and comfort of farm animals. Lying behavior is often used as an indication of well-being in cattle and for evaluating the stall quality. The use of electronic data loggers to automate behavioral recording has become increasingly common. We tested the use of the Pedometer Plus tag (S.A.E. Afikim, Israel) for measuring the lying behavior of dairy cattle ($n=18$ lactating cows). Behavior was recorded for 11 days with the Pedometer Plus tag, from which the rest bout, bout duration and rest time were calculated. The lying behavior was simultaneously recorded using a HOBO Pendant G logger as a reference system to validate the Pedometer Plus tag. A linear regression analysis between the measurement methods showed that the recorded lying time ($R^2 \geq 0.948$) and the recorded number of lying bouts ($R^2 \geq 0.718$) were closely related, which was also confirmed by the comparison of the means (lying time, $P=0.60$; lying bouts, $P=0.72$). Despite the positive relationship, in some days, slope and intercept were statistically different from 1 and 0, respectively. The recordings of lying time and the number of lying bouts between the devices, for some cows, differed by more than 5%. The Pedometer Plus tag overestimates the number of lying bouts and underestimates the time that cows spend lying down with respect to HOBO pendant G logger recording. The different sampling, editing and filtering methods between devices may contribute to these discrepancies. This system will be advantageous for the reliable, 24 h/d automated recording of individual animals in a herd. This system reduces the difficulty of performing continuous measurements of behavior for a large number of animals over a prolonged period of time. In summary, the Pedometer Plus tag is likely a useful tool for the measurement of lying behavior in dairy cows.

1. Introduction

Changes in the behavioral patterns of dairy cows are used by farmers and animal health professionals to identify poor health (e.g., lameness) and reproductive state (e.g., estrus). Behavioral monitoring may be useful to assess animal welfare, health state and productivity in farm animals. In dairy cattle, lying down is a high-priority behavior and is influenced by her social ranking (Galindo and Broom, 2000) as well as her production and health status (Fregonesi and Leaver, 2001). Measures of lying behavior are important measures of cow comfort, providing valuable information on how cows interact with their environment (Tucker et al., 2004; O'DriScoll et al., 2008). The duration and frequency of lying behavior (particularly the time spent lying down, the frequency of lying bouts and the duration of individual lying bouts) were identified as sensitive measures of stall comfort (Haley et al., 2000) and are usable indicators to assess the welfare of lactating dairy

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cows (Fregonesi and Leaver, 2001). The time spent lying down (an increase and a decrease) is also associated with lameness, suggesting that these behavioral measures can help to identify lame cows (Chapinal et al., 2010). Several studies of lying time in cows housed in free-stalls have reported that on an average, a typical dairy cow spends approximately 11.0 h/d lying down (Cook et al., 2005; Ito et al., 2009; Wechsler et al., 2000). Lying behavior in free-stall barns is affected by design and management factors, including the stall surface and bedding quality (Fregonesi et al., 2007b; Tucker et al., 2003), the stall size and configuration (Tucker et al., 2004, 2006), the stocking density (Fregonesi et al., 2007a), the stall location and pen layout (Wagner-Storch et al., 2003), the pen flooring (Fregonesi et al., 2004) and the management of milking and feeding (DeVries and von Keyserlingk, 2005).

Measuring lying behavior in dairy cows can be time consuming and labor intensive if direct or video-based observations are used as recording techniques. Recently, new methods have been developed for automatically recording animal behavior under commercial conditions. Behavioral activity can be recorded by a variety of methods, but accelerometer technology has increased in popularity. Electronic data loggers can be used to accurately measure lying behavior, including the total time spent lying down (Robert et al., 2009), the number of lying bouts (Müller and Schrader, 2003; McGowan et al., 2007; Darr and Epperson, 2009), the duration of each lying bout for individual cows (O'DriScoll et al., 2008) and the laterality of their lying behavior (Ledgerwood et al., 2010). The development of dairy farming to more intensive production systems increased the need for 'real-time' information recorded. Continuous automated monitoring over 24-h periods of behavior for applications on commercial farms could help farmers and veterinarians to assess cow comfort, welfare and health state, especially in livestock with a large number of cows per herd, high level of automation and elevated individual cow milk production. This can be achieved only by integrated monitoring systems and sensors to get a wider range of information (Halachmi et al., 2000).

The objective of this study was to evaluate the use of the Pedometer Plus tag for measuring the lying behavior (total lying time and number of lying bouts) of cows when used as a cow comfort, health (lameness detection) and reproductive state assessment system, for improving management procedures and facilities at the herd level.

2. Materials and methods

We collected the data for this study at a Volcani Center research farm in such a way that our monitoring actions and procedures did not affect the behavior of the cows and did not change the comfort or welfare of the animals monitored.

2.1. Animal

This study was conducted in July 2011 at the Institute of Animal Sciences on the Volcani Center research farm in Bet Dagan (Israel). The Volcani Center research farm is a typical commercial Israeli dairy open cowshed. To evaluate the accuracy of the Pedometer Plus tag for determining lying behavior, 20 lactating cows (Israeli Holstein), eight primiparous cows and 12 multiparous cows (parity $= 2.5 \pm 1.7$; mean $\pm$ SD) were included in the study. The animals were housed within a group of 92 animals and averaged 215.4 ± 167.4 days in milk (DIM) at the beginning of the data collection period. They had an average weight of 597 ± 131 kg and a body condition score BCS of 3.0 ± 0.6 on a scale of 1–5 (Ferguson et al., 1994). The cows were housed in a loose-covered pen (75 m $\times$ 30 m) that was cooled during hot weather conditions. Cows had free access to water and feed and were removed from the pen for milking three times a day at 05:30, 13:35 and 21:00 h. Cows were exposed to a cooling session before each milking (0.6 ± 0.2 h/milking including the milking time, waiting time and cooling time). Between milkings, all cows received cooling showers in the milking yard two times per day, from 08:10 to 08:45 and from 16:10 to 16:55, for further cooling session. They were standing during this time.

During the study, the average temperature was 27.5 °C with a minimum of 23.3 °C and a maximum of 31.8 °C. The average relative humidity was 69%, which was equivalent to an average maximum temperature humidity index (THI) of 80.8 (García-Ispierto et al., 2007).

2.2. Behavioral recordings

Lying behavior was recorded for 11 days by a Pedometer Plus tag and a HOBO Pendant G logger. The Pedometer Plus tag (S.A.E. Afikim, Israel) provides information regarding lying time and lying bouts by a posture sensor including an omni-directional tilt switch to sense a tilt in orientation above an operating angle. From this information, the device calculates some behavioral measurements, including the rest time (the time that cow is lying down), the rest bout (the number of the lying bouts) and the average lying bout duration (lying time/lying bout). The Pedometer Plus tag is an electronic device that records and reports animal behavioral activities based on leg movements. The device has a rigid plastic housing designed to withstand farm environments and attaches with a strap to the lateral side of the leg above the fetlock, between the knee and the hoof, and the operating angle of posture sensor may be set to an angle that may correspond to a tilt of the leg while the animal is in lying position, approximately 60°. During each milking event, the accumulated activity data were transmitted by antennas placed in the milking parlor to the Afifarm management software (S.A.E. Afikim, Israel). The recorded data were analyzed by the Afifarm software that calculates the number of lying bouts, bout duration (min) and rest time (min) for each period between the three milkings (05:30 and 13:30 h; 13:30 and 21:00 h; 21:00 and 05:30 h). Standing and/or lying positions are only recorded when the sensor outputs a stable signal for at least a defined period of time, i.e. 1 min for standing and 3 min for lying. Using the Afifarm software, data can be saved for 40–45 days and show the last 10 days of data for each cow. Eleven days of experimental data for each cow were exported to an Excel 2007 spreadsheet (Microsoft Corp., Redmond, WA).

The Pedometer Plus tags were tested against the HOBO Pendant G loggers (Onset Computer Corporation, Pocasset, MA), which were previously validated for recording standing and lying behavior in dairy cows (Ito et al., 2009; Ledgerwood et al., 2010). The HOBO Pendant G is a waterproof 3-channel data logger. This data logger uses an internal 3-axis accelerometer with a range of ± 3 g. The data loggers were attached to the lateral side of the left or right hind leg of the cows using Vet-flex such that the *x*-axis was perpendicular to the ground and pointing toward the back of the cow (dorsal direction). The allocation of the devices to either the right or left leg was random and was balanced between legs. The data loggers were programmed to record *g*-force at 1 min intervals following the procedure of Ito et al. (2009). Following the approach of Endres and Barberg (2007), we ignored any standing and lying bouts shorter than 2 min based on the assumption that they were associated with leg movements at the recording time. The *g*-force readings from the *x*-axis were used to evaluate lying and standing behavior (Ledgerwood et al., 2010).

A total of 20 cows were monitored, but only 18 cows had usable lying behavior data. The two cows were removed from the study set because a HOBO Pendant G logger was lost, and a Pedometer Plus tag malfunctioned during the experiment. Thus, the final data set consisted of 18 cows monitored over 11 days.

2.3. Statistical analyses

Daily behavioral data were presented on a 24-h basis to facilitate comparisons between the Pedometer Plus tags and the HOBO Pendant G loggers, and to simplify comparisons with existing literature. The Kolmogorov–Smirnov test revealed that the number of lying bouts (bouts/d) was not normally distributed. We applied natural logarithmic transformations ($\log(x)$) to achieve normal distributions. Estimates of lying time (h/d) and the number of lying bouts (bouts/d) for each cow and day were obtained from the Pedometer Plus tag (as dependent variable) and compared with the values obtained from the HOBO Pendant G logger (as independent variable) using a linear regression (PROC REG; SAS Institute, 2004), separately for each day ($n = 18$/day). Additional test statements were included to evaluate whether slope = 1 and intercept = 0. The differences between two devices on estimates of lying time and the number of lying bouts for overall data (ALL) were tested by one-sample paired *t*-tests using transformed data ($n = 18$ cows). The least-squares mean (LSM) and the standard error of the mean (SEM) were determined using the LSMEANS and STDERR statement in PROC GLM (SAS Institute, 2004). For statistical analyses, significance was declared at $P < 0.05$ ($^{*}P < 0.05$; $^{**}P < 0.01$). The lying bout duration was excluded from the statistical analyses because it was not measured but only calculated.

3. Results

The average total lying time (h/d) that was obtained from the Pedometer Plus tag readings was 8.7 ± 2.3 h/d (mean $\pm$ standard deviation). This reading was equivalent to 36% of the day, and had a maximum and minimum of 14.5 and 2.3 h/d, respectively. A mean of 12.1 lying bouts was observed by the Pedometer Plus tag, ranging from 5 to 20 lying bouts per cow/d. Dividing the lying time by the number of lying bouts per day resulted an average lying bout duration of 46.1 ± 19.3 min.

A close relationship between the Pedometer Plus tag and the HOBO Pendant G logger was found for lying times ($R^2 = 0.983$, and the adjusted $R^2 = 0.983$ with $P < 0.001$) and the number of lying bouts ($R^2 = 0.808$, and adjusted $R^2 = 0.807$; $P < 0.001$) (Fig. 1). The linear regression analysis for each day (Table 1) confirmed the clear relationship between the Pedometer Plus tag and the HOBO Pendant G logger for lying times ($R^2 \geq 0.948$) and the number of lying bouts ($R^2 \geq 0.718$). Despite the positive relationship, the value of intercept of lying time resulted constantly negative and significantly greater than 0 for at least six out of the 11 monitored days (Table 1). Instead, for the number of lying bouts the intercept value resulted ever positive, with one exception, and significantly greater than 0 for only 3

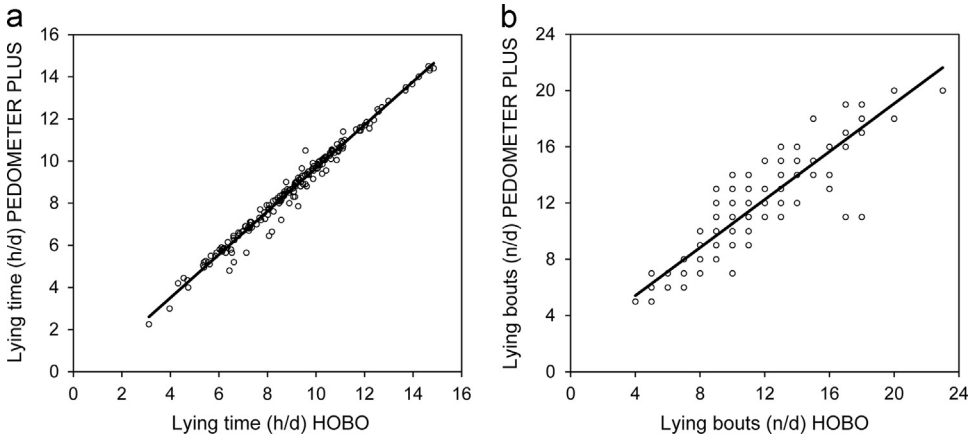

Fig. 1. Here, the relationships between the Pedometer Plus tag (dependent variable) and the HOBO Pendant G logger (independent variable) readings, based on 18 cows monitored over 11 days, are shown. (a) The correlation of measured lying time (h/d) and (b) the correlation of the number of lying bouts (n/d).

Table 1
Regression statistic parameters of lying time and lying bouts recorded between the Pedometer Plus tag (dependent variable) and the HOBO Pendant G logger (independent variable) separately for each day ($n=18$/day) are shown.

Day	Lying time			Lying bout		
	R^2	Intercept	Slope	R^2	Intercept	Slope
1	0.948	−0.851	1.047	0.742	1.857	0.841
2	0.986	−0.283	0.992	0.885	0.678	0.985
3	0.986	−0.767*	1.044	0.718	2.775	0.740*
4	0.968	−0.796	1.044	0.85	2.644*	0.834
5	0.989	−0.560*	1.021	0.804	2.285	0.859
6	0.994	−0.619**	1.032	0.838	1.847	0.872
7	0.996	−0.114	0.98	0.853	2.397*	0.812*
8	0.974	−0.984*	1.071	0.754	−0.473	1.079
9	0.991	−0.635*	1.035	0.817	2.838*	0.799
10	0.994	−0.603*	1.024	0.858	1.559	0.878
11	0.977	−0.619	1.027	0.884	2.104	0.856

* $P<0.05$, significance of the slope and intercept differed from 1 and 0, respectively.
** $P<0.01$, significance of the slope and intercept differed from 1 and 0, respectively.

days ($P<0.05$). Slope resulted significantly different ($P<0.05$) from 1 for only 2 days for lying bouts.

The different percentages of lying time and the number of lying bouts between the HOBO Pendant G logger and the Pedometer Plus tag data for all cows and across individual cows are shown in Fig. 2. For data recorded by the HOBO Pendant G logger, the number of lying bouts was overestimated by the Pedometer Plus tag, but the lying time was underestimated, as confirmed also by the linear regression analysis. All cows had a 4% difference in behavioral data between measurement methods. Notable inter-individual variability was found between cows. The difference in lying time between the Pedometer Plus tag and the HOBO Pendant G logger ranged from 0% to 13%, and the difference in the number of lying bouts ranged from 0% to 20%. There was no difference in lying time and the number of lying bouts measured between the Pedometer Plus tag and the HOBO Pendant G logger for comparison between all cows (lying time, $P=0.60$; lying bouts, $P=0.72$).

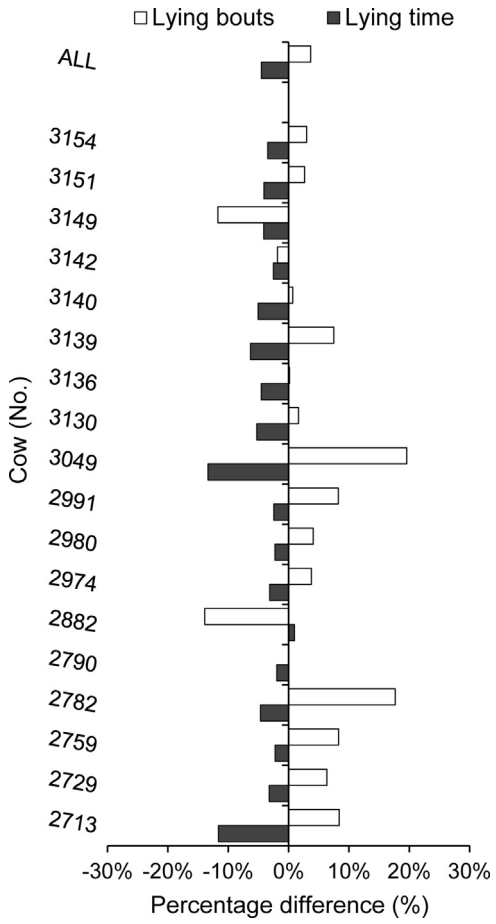

Fig. 2. Here, the percent difference between the time that cows spent lying (h/d) and the number of lying bouts (n/d) between the HOBO Pendant G logger and the Pedometer Plus tag measurements data is shown. Bars on the right (positive difference) show that the Pedometer Plus tag overestimated lying behavior (time and number of lying bouts) relative to the HOBO Pendant G logger; however, the bars on the left show the opposite trend. Mean data are shown separately for all cows and by each individual cow (cow, no.).

4. Discussion

In this study, cows spent 8.6 h/d lying down. These values are lower with respect to 11.0 h/d reported in the literature (Cook et al., 2005; Ito et al., 2009; Wechsler et al., 2000). The amount of time that cows spent lying down was affected by the milking management, such as the three milking periods per day and the cooling and waiting time before each milking. In particular, the further cooling showers in the milking yard that the cows received each day between milkings from 08:10 to 08:45 h and from 16:10 to 16:55 h to reduce the effects of heat load in summer conditions likely affected their lying time. During these two periods of the day, cows were forced standing in the milking yard reducing the potential daily lying time. Cattle also spend less time lying down in warmer conditions (Brown-Brandl et al., 2006; Cook et al., 2007; Overton et al., 2002).

The current study demonstrated that the Pedometer Plus tag can measure reliably the lying behavior (lying time and lying bouts), comparing to the HOBO Pendant G logger in lactating dairy cows in a loose-housing system. The linear regression analysis showed close relationships of the lying time and the number of lying bouts between the Pedometer Plus tag and the HOBO Pendant G logger. The capability of the Pedometer Plus tag to measure the lying behavior was partially confirmed by test of the intercept and slope, which showed, in some days, that the slope and intercept were statistically different from 1 and 0, respectively. Moreover, for some cows the recordings of lying time and the number of lying bouts between the devices differed by more than 5%. Some experiments have shown that the differences in the lying time and the lying bouts recorded with automatic recording systems may result from differences in device placement (Müller and Schrader, 2003), time discrepancies between the different tags or differences in sampling interval and data processing methods used to identify the lying time

and the number of lying bouts (Ledgerwood et al., 2010). However, in preliminary studies using these devices the influence of the device placement was not significant, and the application of the device to the rear leg minimized any small differences (Müller and Schrader, 2003). Relative to the HOBO Pendant G logger that was validated by several authors (Ito et al., 2009; Ledgerwood et al., 2010), the Pedometer Plus tag overestimates the number of lying bouts and underestimates the time that cows spend lying down. This inconsistency most likely is due to the device calculation software of the Pedometer Plus. Particularly, Pedometer Plus tag utilizes an operative angle to identify lying events not always able to discriminate all lying events. Sometimes, during lying down period, cow could assume a particular position of the leg recognized by the system as a standing event. The overestimation of lying bouts by the Pedometer Plus tag could depend on the filtering method of standing events. Pedometer Plus tag uses a filtering period of 1 min for standing, while HOBO logger has been used with 2 min to remove potentially erroneous readings of standing events. This difference increases the number of lying bouts and decreases slightly lying time recorded by the Pedometer Plus tag. In this case, the standing filter of Pedometer Plus tag can result more reliable than the filter used by the HOBO logger. Here, the different sampling, editing and filtering methods explain the discrepancies between the lying time and the number of lying bouts recorded. An improved processing algorithm for recorded data might enhance the equipment performance.

Video observation over 24-h periods, especially for a group of animals housed together, can be technically challenging, labor intensive and time consuming and for this reason the HOBO Pendant G logger was used to record lying behavior in our study as a gold standard to assess the reliability of Pedometer Plus tag. Anyway, the use of HOBO Pendant G logger as the gold standard could introduce an error in the estimation of behavior since there is inherent error in the HOBO logger that may be “propagated” by using one logger to evaluate another. However, HOBO has been recognized as a valid reference method in previous studies (Ito et al., 2009; Ledgerwood et al., 2010).

The Pedometer Plus tag records lying behavior (lying time and lying bouts) of each cow 24 h/d. The integration of these new data in a computerized farm management system creates new opportunities for herd managers and researchers to focus on investigating improvement of housing and other facilities conditions as well as management procedures. The integration of the lying behavior data can advance precision dairy farming and could be used for developing objective and automatic parameters to assess cow welfare and comfort, improving detection of health disorders and reducing time for detection. This system will have the advantage of automatically recording reliable data 24 h/d on individual herd members, thereby reducing the difficulty of continuously measuring and monitoring such behavior for prolonged periods of time on a large number of animals. Furthermore, the integration of these data with other data collected by the herd management system (milk quantity, milk conductivity, milk components, body weight and body condition score) will potentially improve and fine tune the system assessment.

5. Conclusions

The Pedometer Plus tag appears to be a useful tool for the measurement of the number of lying bouts and the lying time of dairy cows, which makes it a useful device for future research.

Improvements in data processing might enhance the performances of this device, and it would be interesting to understand how the continuous recording of behavioral patterns will support the early warning capability of the herd management system.

The automated measurement of lying behavior can reduce labor requirements for the research assessment of cow behavior and can be a powerful management tool for monitoring and improve understanding of comfort and welfare of dairy cows under the intensive conditions of modern farms.

Conflict of interest

There is no conflict of interest.

Acknowledgments

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References

Brown-Brandl, T.M., Nienaber, J.A., Eigenberg, R.A., Mader, T.L., Morrow, J. L., Dailey, J.W., 2006. Comparison of heat tolerance of feedlot heifers of different breeds. Livest. Sci. 105, 19–26.
Chapinal, N., de Passillé, A.M., Rushen, J., 2010. Correlated changes in behavioral indicators of lameness in dairy cows following hoof trimming. J. Dairy Sci. 93, 5758–5763.
Cook, N.B., Bennett, T.B., Nordlund, K.V., 2005. Monitoring indices of cow comfort in free-stall-housed dairy herds. J. Dairy Sci. 88, 3876–3885.
Cook, N.B., Mentink, R.L., Bennett, T.B., Burgi, K., 2007. The effects of heat stress and lameness on time budgets of lactating dairy cows. J. Dairy Sci. 90, 1674–1682.
Darr, M., Epperson, W., 2009. Embedded sensor technology for real time determination of animal lying time. Comput. Electron. Agric. 66, 106–111.
DeVries, T.J., von Keyserlingk, M.A.G., 2005. Time of feed delivery affects the feeding and lying patterns of dairy cows. J. Dairy Sci. 88, 625–631.
Endres, M.I., Barberg, A.E., 2007. Behavior of dairy cows in an alternative bedded-pack housing system. J. Dairy Sci. 90, 4192–4200.
Ferguson, J.D., Galligan, T.D., Thomsen, N., 1994. Principal descriptors of body condition score in Holstein cows. J. Dairy Sci. 77, 2695–2703.
Fregonesi, J.A., Leaver, J.D., 2001. Behaviour, performance and health indicators of welfare for dairy cows housed in strawyard or cubicle systems. Livest. Prod. Sci. 68, 205–216.
Fregonesi, J.A., Tucker, C.B., Weary, D.M., 2007a. Overstocking reduces lying time in dairy cows. J. Dairy Sci. 90, 3349–3354.
Fregonesi, J.A., Tucker, C.B., Weary, D.M., Flower, F.C., Vittle, T., 2004. Effect of rubber flooring in front of the feed bunk on the time budgets of dairy cattle. J. Dairy Sci. 87, 1203–1207.
Fregonesi, J.A., Veira, D.M., von Keyserlingk, M.A.G., Weary, D.M., 2007b. Effects of bedding quality on lying behavior of dairy cows. J. Dairy Sci. 90, 5468–5472.

Galindo, F., Broom., D.M., 2000. The relationships between social behaviour of dairy cows and the occurrence of lameness in three herds. Res. Vet. Sci. 69, 75–79.
García-Ispierto, I., López-Gatius, F., Bech-Sabat, G., Santolaria, P., Yániz, J. L., Nogareda, C., De Rensis, F., López-Béjar, M., 2007. Climate factors affecting conception rate of high producing dairy cows in northeastern Spain. Theriogenology 67, 1379–1385.
Halachmi, I., Metz, J.H.M., Maltz, E., Dijkhuizen, A.A., Speelma, L., 2000. Designing the optimal robotic milking barn. Part 1: quantifying facility usage. J. Agric. Eng. Res 76, 37–49.
Haley, D.B., Rushen, J., de Passillé, A.M., 2000. Behavioural indicators of cow comfort: activity and resting behaviour of dairy cows in two types of housing. Can. J. Anim. Sci. 80, 257–263.
Ito, K., Weary, D.M., von Keyserlingk, M.A.G., 2009. Lying behavior: assessing within- and between-herd variation in free-stall-housed dairy cows. J. Dairy Sci. 92, 4412–4420.
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.
McGowan, J.E., Burke, C.R., Jago, J.G., 2007. Validation of a technology for objectively measuring behaviour in dairy cows and its application for oestrous detection. NZ Soc. Anim. Prod. 67, 136–142.
Müller, R., Schrader, L., 2003. A new method to measure behavioural activity levels in dairy cows. Appl. Anim. Behav. Sci. 83, 247–258.
O'DriScoll, K., Boyle, L., Hanlon, A., 2008. A brief note on the validation of a system for recording lying behaviour in dairy cows. Appl. Anim. Behav. Sci. 111, 195–200.
Overton, M.W., Sischo, W.M., Temple, G.D., Moore, D.A., 2002. Using timelapse video photography to assess dairy cattle lying behavior in a freestall barn. J. Dairy Sci. 85, 2407–2413.
Robert, B., White, B.J., Renter, D.G., Larson, R.L., 2009. Evaluation of three-dimensional accelerometers to monitor and classify behavior patterns in cattle. Comp. Electr. Agric. 67, 80–84.
SAS Institute. 2004. SAS/Stat 9.1 User's Guide. SAS Inst. Inc., Cary, NC.
Tucker, C.B., Weary, D.M., Fraser, D., 2003. Effects of three types of freestall surfaces on preferences and stall usage by dairy cows. J. Dairy Sci. 86, 521–529.
Tucker, C.B., Weary, D.M., Fraser, D., 2004. Free-stall dimensions: effects on preference and stall usage. J. Dairy Sci. 87, 1208–1216.
Tucker, C.B., Zdanowicz, G., Weary, D.M., 2006. Brisket boards reduce freestall use. J. Dairy Sci. 89, 2603–2607.
Wagner-Storch, A.M., Palmer, R.W., Kammel, D.W., 2003. Factors affecting stall use for different freestall bases. J. Dairy Sci. 86, 2253–2266.
Wechsler, B., Schaub, J., Friedli, K., Hauser, R., 2000. Behaviour and leg injuries in dairy cows kept in cubicle systems with straw bedding or soft lying mats. Appl. Anim. Behav. Sci. 69, 189–197.