Sampling cows to assess lying time for on-farm animal welfare assessment

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ABSTRACT

The time that dairy cows spend lying down is an important measure of their welfare, and data loggers can be used to automatically monitor lying time on commercial farms. To determine how the number of days of sampling, parity, stage of lactation, and production level affect lying time, electronic data loggers were used to record lying time for 10 d consecutively, at 3 stages of lactation [early: when cows were at 10–40 d in milk (DIM), mid: 100–140 DIM, late: 200–240 DIM] of 96 Holstein cows in tiestalls (TS) and 127 in freestalls (FS). We calculated daily duration of lying, bout frequency, and mean bout duration. We observed complex interactions between parity and stage of lactation, which differed somewhat between tiestalls and freestalls. First-parity cows had higher bout frequency and shorter lying bouts than older cows but bout frequency decreased and mean bout duration increased as DIM increased. We found that individual cows were not consistent in time spent lying between early and mid lactation (Pearson coefficient, TS: $r = 0.1$, FS: $r = 0.2$), whereas cows seemed to be more consistent in time spent lying between mid and late lactation (TS: $r = 0.7$, FS: $r = 0.3$). For both TS and FS cows, daily milk production was significantly, but slightly negatively, correlated with lying time across the lactation (range, $r: -0.2$ to -0.4), whereas parity was slightly to moderately positively correlated with mean bout duration across the lactation ($r: +0.2$ to $+0.6$) and negatively with bout frequency ($r: -0.2$ to -0.5). To estimate how the duration of the time sample affected the estimates of lying time subsets of data subsets consisting of 1, 2, 3, 4, 5, 6, 7, 8, and 9 d per cow were created, and the relationship between the overall mean (based on 10 d) and the mean of each subset was tested by regression. For both TS and FS, lying time based on 4 d of sampling provided good estimates of the average 10-d

estimate (90% of accuracy). Automated monitoring of lying time has potential as a measure of dairy cow welfare on commercial farms but cows differ greatly in lying time. To obtain a representative measure for the herd, it is necessary to sample cows based on their parity and stage of lactation but probably not milk production level.

Key words: lying time, dairy cow, tiestall, freestall

INTRODUCTION

The measures for assessing animal welfare are conventionally divided into input-based measures, which describe the environment of the animal or the management practices used, and outcome- or animal-based measures, which describe the actual state of the animal (Rushen et al., 2008; Knierim and Winckler, 2009). One advantage of outcome-based measures is that they can be used to compare the welfare of animals housed in very different types of housing systems. However, outcome-based measures can be time consuming to record and it is often difficult to ensure inter-assessor reliability (Rushen et al., 2011). Therefore, the use of automated methods to record outcome-based measures of welfare would be a great asset.

Lying time has been used as a measure of dairy cow welfare and automated monitoring of lying time has been used to assess cow welfare on commercial farms (Ito et al., 2009). The average time that cows lie down each day varies, depending on, for example, aspects of stall design. Uncomfortable conditions (hard floors, wet bedding, or small stalls) reduce cow lying time (e.g., Haley et al., 2000) and reduced lying time has been associated with higher incidence of injuries (e.g., Rushen et al., 2007). Stall design and its association with injuries is not the only factor affecting lying time. Research suggests that lameness is preceded by a period of reduced lying time (Chapinal et al., 2009; Proudfoot et al., 2010), and lame cows subsequently lay down more (Chapinal et al., 2009, 2010a,b). Finally, behavioral and physiological changes in cows prevented from lying down suggest that prevention of lying is stressful (Munksgaard and Løvendahl, 1993; Munksgaard and Simonsen, 1996; Fisher et al., 2002). Therefore, auto-

Received November 22, 2011.

Accepted May 7, 2012.

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mated measurement of lying time has a lot of potential as an outcome measure to assess welfare on commercial dairies.

Although the total daily duration of time spent lying is the measure most commonly used, measures of bout frequency and bout duration may also be informative. Haley et al. (2001) showed that cows in tiestalls with hard floors lay down less frequently but in longer bouts than cows in stalls with softer floors. This may reflect discomfort experienced by the cows during the process of standing up and lying down.

Ito et al. (2009)'s study of Canadian dairy farms showed that the variation between farms in the average time spent lying down each day was small, but that the variation between cows was much larger. Thus, to effectively use lying time as a herd-level measure of dairy cow welfare in commercial farm situations, we need to obtain a representative measure of lying time of the herd and we need to know how to sample cows with respect to individual differences and other factors that may influence lying time such as parity (Singh et al., 1993), stage of lactation (Olmos et al., 2009), and milk production level (Fregonesi and Leaver, 2002). The duration of the sampling period is another important aspect to consider when measuring average lying time in a herd. Ito et al. (2009) suggested that a sampling period of 4 d is sufficient to obtain a representative estimate of lying time in large freestall herds, and whether this is the same for tiestalls needs to be confirmed.

In this study, we did the analyses from the perspective of an auditor or animal welfare assessor needing to choose a sample of cows from which to take measures of lying time. Therefore, to estimate if these factors need to be taken in account when sampling cows, the effect of number of days sampled, parity, stage of lactation, and milk production level on lying time of dairy cows in tiestall (**TS**) and freestall (**FS**) housing was evaluated. Three variables of lying behavior were examined: daily duration of lying, bout frequency, and mean bout duration. In addition, we tested if the differences between individual cows in lying time were constant over the lactation.

MATERIALS AND METHODS

Animals and Housing

Tiestall Cows. We used 96 lactating Holstein cows [parity range 1–6 with 48% of cows in parity 1; multiparous cows 305-d mature-equivalent milk yield (**305ME**) mean $\pm$ SD = 11,452 kg $\pm$ 1,072 kg] from the University of Guelph's dairy research center (Elora, ON, Canada) housed in tiestalls (bed: 1.88 m long $\times$ 1.15 m wide; chain length 0.53–0.56 m) with a stall base of geotextile

mattress (Pasture Mat, Promat Inc., Woodstock, ON, Canada) covered with a layer of chopped straw. The TS cows were fed a TMR diet 3 times daily, at approximately 0530, 1300, and 1600 h, that was formulated to meet requirements for lactating dairy cows (NRC, 2001). Water was freely available from water bowls (1 for 2 neighboring cows). Cows were milked twice daily in a parlor at approximately 0430 and 1445 h.

Freestall Cows. We used 127 lactating Holstein cows (parity range 1–9 with 34% of cows in parity 1; multiparous cows 305ME yield mean $\pm$ SD = 11,496 kg $\pm$ 1,690 kg) from the University of British Columbia's dairy research center (Agassiz, BC, Canada) housed in sand-bedded freestalls (2.4 m long $\times$ 1.18 m wide $\times$ 0.40 m deep, at least 1 per cow, in pens ranging from 12 to 48 cows). The routine management of the cows involved relocating the cows in new pens on a regular basis. First- and higher-parity cows were mixed together in pens. The FS cows were fed a TMR diet twice daily, at 0700 and 1600 h, that was formulated to meet requirements for lactating dairy cows (NRC, 2001). Water was freely available from self-filling troughs. Lactating cows were milked twice daily in a parlor at approximately 0800 and 1700 h.

Data Collection

Data collection took place over a year and was continuous (no clearly defined periods). Measures of lying time were collected over consecutive 10-d periods in 3 stages of lactation: early lactation (when animals were between 10 and 40 DIM), mid lactation (between 100 and 140 DIM), and late lactation (between 200 and 240 DIM). At each stage, parity and daily milk production (based on 10-d average) were recorded (Table 1). Cows with identified health issues for the period from 10 d before until 10 d after data collection, as well as cows hoof-trimmed during the 10 d of data collection, were removed from the data set.

Lying Time

Electronic data loggers were used to record lying behavior of the focal cows (tiestalls: Afimilk Pedometer, S.A.E. Afikim, Kibbutz Afikim, Israel; freestalls: Tinytag Plus, Gemini Dataloggers Ltd., Chichester, UK; Hobo Pendant G Acceleration Data Loggers, Onset Computer Corp., Pocasset, MA). The 3 loggers were previously validated for recording standing and lying behavior in dairy cows, and the 2 types used for FS cows have been tested against each other (O'Driscoll et al., 2008; Ito et al., 2009; Higginson et al., 2010). For each focal cow, only one type of data logger was used. The data logger was placed in a fabric pouch and

Table 1. Number of cows and daily milk production (mean $\pm$ SD, kg of milk/d) at 3 stages of lactation (early, mid, and late) for tiestall- and freestall-housed cows

Group	Lactation stage		
	Early	Mid	Late
Tiestall			
No. of cows	82	73	45
Daily milk production	39.2 $\pm$ 7.4	37.9 $\pm$ 6.3	32.0 $\pm$ 6.3
Freestall			
No. of cows	73	91	105
Daily milk production	41.7 $\pm$ 10.4	39.2 $\pm$ 8.8	31.6 $\pm$ 7.3

attached to a hind leg of each FS cow using Vet-Wrap (CoFolex, Andover Coated Products Inc., Salisbury, MA) or directly attached to a hind leg of each TS cow using a Velcro strap (Velcro USA Inc., Manchester, NH). The data logger was programmed to record position of the cow (lying or standing) at 1-min intervals for 10 d. Data were downloaded twice a day at milking for TS cows or downloaded once the data loggers were removed after each 10-d period of data collection for FS cows. Durations of individual lying bouts were computed using Excel macros (Microsoft Corp., Redmond, WA) for each 10-d period.

Statistical Analysis

All statistical analyses were performed using SAS software (version 9.2; SAS Institute Inc., Cary, NC). Analyses were done separately for TS and FS cows. We did the analyses from the perspective of a possible auditor or animal welfare assessor needing to choose a sample of cows from which to take measures of lying time. Information on the parity and stage of lactation would likely be available for most or all farms and could be used to select cows in advance. Therefore, we did our main analyses using these variables. Measures of milk production would not be available from many farms or could only be obtained with difficulty (and milk production from the previous lactation would not be available for primiparous cows). Therefore, we did not include this in our initial model, as inclusion may have reduced the effect of parity and stage of lactation. We did secondary regressions to see if including milk production would help in selecting cows on farms where this information was available.

To determine how stage of lactation affected the estimates of lying time, only focal cows followed at 2 or 3 stages of lactation during the same lactation were used ($n = 83$ TS cows; $n = 112$ FS cows). The overall averages based on 10 d (or a minimum of 7 d when there were missing values) were calculated for daily duration of lying time (h/d), bout frequency (bout/d), and mean bout duration (min/bout) for each cow.

Compliance with the assumptions of normality and homogeneity of variances were checked using the UNIVARIATE procedure. Natural logarithmic transformation was applied to bout frequency and mean bout duration to normalize these distributions. We checked for extreme outliers (3 times the interquartile range outside of the interquartile limits) but none were removed from analyses. The differences in lying time between the 3 stages of lactation were tested using a generalized linear mixed model (GLIMMIX) with cow as random effect and stage of lactation as factor. Parity was forced into all models to look at the interaction of stage of lactation and parity on lying time. Parity was classified as primiparous or multiparous. Least squares means of each lying variable were back-transformed where applicable.

Pearson coefficients of correlation (using procedure CORR) across cows between the different stages of lactation within the same parity were calculated to verify if the individual differences in lying time were stable across the lactation (no. of cows early to mid and mid to late: $n = 59$ and 27 cows, respectively, for TS, and $n = 46$ and 64 for FS).

To test the effect of parity, daily milk production, and 305ME yield on lying time at each stage of lactation (early, mid, and late), regressions (using the procedure REG, forward stepwise regression selection model, level of significance to enter into the model was $P < 0.05$) were calculated separately. Regressions were run with the 3 variables on multiparous cows only (no. of cows for early, mid, and late: $n = 26$, 33 , and 20 cows, respectively, for TS, and $n = 32$, 62 , and 54 for FS) to test the effect of 305ME yield; then, regressions were run only with the 2 variables parity and daily milk production on all cows (no. of cows for early, mid, and late: $n = 68$, 73 , and 33 cows, respectively, for TS, and $n = 50$, 90 , and 83 for FS). Parity was classified as 1, 2, 3, or ≥ 4 .

To estimate how the duration of the time sample affected the estimates of lying time, focal cows with complete data for 10 d at 1, 2 or 3 stages of lactation (TS: $n = 170$; FS: $n = 234$) were used to create subsets

of data consisting of 1 d, 2 d, 3 d, 4 d, 5 d, 6 d, 7 d, 8 d, 9 d per cow by using simple random sampling in PROC SURVEYSELECT with strata specified as cow and stage of lactation. The procedure was repeated 10 times for each subset, and the relationship between the overall mean (based on 10 d) and the mean of each subset was tested using a regression model (PROC REG). The 10 R^2 values resulting from the 10 repetitions of the procedure for each subset (1 d to 9 d) were averaged to estimate a mean and standard deviation for each subset. Estimates were calculated for daily duration of lying, bout frequency, and mean bout duration.

RESULTS

Effect of Stage of Lactation, Parity, and Milk Production on Lying Time

Complex interactions existed between stage of lactation and parity, which differed somewhat between TS and FS (Table 2). In FS, we observed an effect of stage of lactation, with no interaction between stage and parity for daily duration of lying; the daily duration of lying increased with stage of lactation in primiparous and multiparous cows (Figure 1a). In first-parity cows, this increase in daily duration of lying with stage of lactation was associated with increased bout duration (Figure 1c) and decreased bout frequency (Figure 1b). However, these changes in bout frequency and duration were not as apparent in older cows.

In TS, we observed an interaction between parity and stage of lactation: the daily duration of lying increased regularly over the lactation in the primiparous cows but this increase was less regular in multiparous cows (Figure 1a). A reduced bout frequency (Figure 1b) and increased bout duration (Figure 1c) with increased stage of lactation was observed in primiparous and multiparous cows.

For both TS and FS cows, a nonsignificant correlation was found between early and mid lactation in daily lying duration, but bout frequency and mean bout duration were moderately to highly correlated (Table 3). However, moderate to high correlations were found between mid and late lactation for all 3 variables of lying time (Table 3).

From the regression models run with 305ME yield, we found that 305ME yield was positively associated only at mid lactation with mean duration of lying bout for FS cows ($r = +0.3$; $P < 0.05$). From the regression models run with daily milk production, we found that daily milk production was negatively associated with daily duration of lying time in early lactation for FS cows, and in mid lactation for TS cows (Table 4). Daily milk production was negatively associated with bout frequency in mid lactation for TS cows and with bout duration in late lactation for FS cows (Table 4).

We found no simple effects of parity, even within stages of lactation. Parity was positively associated with lying time only during early lactation in TS but not FS (Table 4). Parity was negatively associated with bout frequency in early and mid lactation and positively associated with bout duration at all stages of lactation in both TS and FS (Table 4).

Effect of Duration of the Time Sample on Lying Time

We tested the relationships between average 10-d estimates of lying time and subsets of 1 to 9 d randomly sampled (Figure 2). For both TS and FS cows, subsets based on a 4-d sample provided good estimates of the average 10-d estimate ($R^2 > 0.9$, $P < 0.001$) for all 3 variables of lying time. A single-day sampling provided estimates with 63 to 80, 69 to 81, and 60 to 72% of accuracy compared with the overall average based on 10 d for daily duration of lying, bout frequency, and mean bout duration, respectively.

Table 2. Test of the effect of stage of lactation (early, mid, and late lactation) and parity (2 classes: primiparous and multiparous) on daily duration of lying, bout frequency, and mean bout duration for tiestall and freestall cows

Item	df	Stage of lactation		Parity		Stage $\times$ parity	
		F	$P > F$	F	$P > F$	F	$P > F$
Tiestall							
Daily duration of lying (h/d)	87	23.2	***	2.1	NS	2.7	†
Bout frequency (bout/d)		8.7	***	16.0	***	0.4	NS
Mean bout duration (min/bout)		47.3	***	22.0	***	3.3	*
Freestall							
Daily duration of lying (h/d)	108	40.6	***	0.5	NS	1.9	NS
Bout frequency (bout/d)		0.5	NS	13.5	***	23.7	***
Mean bout duration (min/bout)		25.0	***	20.1	***	14.9	***

¹Degrees of freedom and type I tests of fixed effects (GLIMMIX procedure, F-value and $P > F$) of stage of lactation, parity, and stage of lactation $\times$ parity interaction are shown for all 3 variables of lying time.

NS = $P > 0.1$; † $P < 0.1$ (tendency); * $P < 0.05$; *** $P < 0.001$.

Figure 1. Mean ($\pm$ SD) daily duration of lying time (a; h/d), bout frequency (b; bout/d), and mean bout duration (c; min/bout) for primiparous and multiparous tiestall (TS) and freestall (FS) cows over the lactation (early, mid, and late lactation). For bout frequency and mean bout duration, back-transformed means with natural log-transformation were applied to the variable.

DISCUSSION

Effect of Stage of Lactation, Parity, and Milk Production on Lying Time

Average daily lying time measured in our study correspond with values reported in previous studies in ti-

estall housing (Rushen et al., 2007; Tucker et al., 2009) and freestall housing (Fregonesi and Leaver, 2002; Fregonesi et al., 2007).

We found complex effects of stage of lactation and parity on lying time, which differed somewhat between FS and TS. In both systems, the daily duration of time spent lying down increased with increased DIM

Table 3. Correlation (r: Pearson coefficient and *P*-value) across tiestall and freestall cows between different stages of lactation for daily duration of lying, bout frequency, and mean bout duration

Group	Between early and mid lactation			Between mid and late lactation		
	n ¹	r	<i>P</i> -value	n	r	<i>P</i> -value
Tiestall						
Daily duration of lying (h/d)	59	0.1	NS	27	0.7	***
Bout frequency (bout/d)		0.6	***		0.5	***
Mean bout duration (min/bout)		0.7	***		0.6	***
Freestall						
Daily duration of lying (h/d)	46	0.2	NS	64	0.3	**
Bout frequency (bout/d)		0.4	**		0.6	***
Mean bout duration (min/bout)		0.3	*		0.4	**

¹n = number of cows.NS = *P* > 0.1; **P* < 0.05; ***P* < 0.01; ****P* < 0.001.

in first-parity cows. This was due to increased bout duration but decreased bout frequency, which suggests that it may be easier for primiparous cows in early lactation to get up and lie down. The effect of increasing DIM on daily duration of lying also occurred in later parities in cows in TS but was not significant in older cows in FS. Previous studies showed an increase in lying time as DIM increased due to an increase in mean bout duration (Nielsen et al., 2000; Chaplin and Munksgaard, 2001; Olmos et al., 2009). However, other research showed that the increase in daily duration of lying as DIM increased may be due to the increase in number of bouts rather than an increase in bout duration (Endres and Barberg, 2007), which is the opposite

of what we found. Our results show that the effect of DIM on lying bout frequency and bout duration varied according to parity, so differences between studies may reflect differences in the ages of the cows studied. It is plausible that cow discomfort while lying (due to added pressure on their distended udder) is higher in early lactation. For this reason, cows spend less time lying down in early lactation, whereas lying time increases as udder distension decreases with progressing DIM. For example, Gleeson et al. (2007) reported the highest udder firmness scores in the first 8 wk following calving, with a decrease thereafter. However, another study showed no increase of udder distension as lactation progressed during the first 12 wk of lactation (O'Driscoll et

Table 4. Selection by stepwise forward regression (r: coefficient of correlation) of the significantly influential variables (parity, daily milk production) affecting lying time (daily duration of lying time, bout frequency, and mean bout duration) at 3 stages of lactation for tiestall and freestall cows

Group	Early			Mid			Late		
	n ¹	Variable ²	r	n	Variable	r	n	Variable	r
Tiestall									
Daily duration of lying (h/d)	68	Parity	+0.3*	73	Daily milk production	−0.3*	33	— ³	—
Bout frequency (bout/d)		Parity	−0.5***		Daily milk production	−0.4***		—	—
Mean bout duration (min/bout)		Parity	+0.6***		Parity	+0.3**		Parity	+0.4*
Freestall									
Daily duration of lying (h/d)	50	Daily milk production	−0.3*	90	—	—	83	—	—
Bout frequency (bout/d)		Parity	−0.5***		Parity	−0.2*		—	—
Mean bout duration (min/bout)		Parity	+0.5***		Parity	+0.2*		Daily milk production	−0.2*
								Parity	+0.3* ⁴

¹n = number of cows.²Significance level entry into the model was *P* < 0.05.³No variable reached the level of significance.⁴r value issued from cumulative R² and reflects the amount of variation described by adding the significant variable to the model.**P* < 0.05; ***P* < 0.01; ****P* < 0.001.

Figure 2. Relationship (R^2) between average 10-d daily duration of lying time (a), bout frequency (b), and mean bout duration (c), and estimates derived from 9, 8, 7, 6, 5, 4, 3, 2, or 1 d randomly sampled for each tiestall (TS) and freestall (FS) cow (TS: $n = 170$; FS: $n = 234$). The standard deviations across the 10 random sampling events were too small to be visible.

al., 2011). In general, however, our results show that it is difficult to draw simple conclusions about the effect of stage of lactation on lying time in cows.

More importantly, the demand for food, and hence time spent feeding, is higher in early compared with late lactation, which should reduce the time available for lying (Jensen et al., 2005). However, effect of stage of lactation on feeding patterns is not consistent through different studies. In freestall-housed cows, DeVries et al. (2003) showed an increase in feeding time of cows from early to peak lactation, whereas no change in feeding behaviors observed over the early part of lactation were found in cows housed in tiestalls (DeVries et al., 2009). Interestingly, the extra 2 h per day spent feeding by early lactation cows reported by DeVries et al. (2003) corresponds to the 2 to 3 h per day less time spent lying down that we found for primiparous cows in our study.

We tested whether differences between cows in lying time were consistent over the lactation to understand how much of the variation in lying time in a herd is due to stable individual differences. We found that individual cows are not consistent in time spent lying between early and mid lactation (i.e., cows that lie less in early lactation are not the same cows that lie less in mid lactation), whereas cows seem to be more consistent in time spent lying between mid and late lactation. Many differences occur in cows between d 10 and 40 and d 100 and 140 of lactation, such as the occurrence of estrus or the beginning of pregnancy, which may affect lying time. Furthermore, some of the differences may reflect subclinical postpartum illness; even if we removed identified sick or lame cows from our sample, some sickness signs of postpartum diseases (e.g., metritis) are more difficult to detect and can go unnoticed until the disease is in its clinical stage (von Keyserlingk et al., 2011). As an example, approximately 30% of the cows of the freestall barn studied were diagnosed with subclinical endometritis in a previous study (Wittrock et al., 2011).

We tested the effect of parity and milk production on lying time to estimate if parity needs to be taken into account when measuring lying time in a herd. Usually, the effects of parity interacted with the effects of stage of lactation, as described above. Within stages of lactation, parity did not consistently affect the daily duration of lying, but the frequency of lying bouts was generally higher and the duration of lying bouts was shorter for first-parity cows compared with older cows. This may reflect either a greater ease in standing up and lying down or a more disrupted rest patterns for younger cows. Similarly, shorter lying times in first-lactation cows have been shown by Singh et al. (1993). In freestall cows, the disruption in lying may be explained

by first-lactation cows having low ranking positions within the group and therefore being displaced by older and more dominant cows. In addition, they are experiencing and adapting to an unfamiliar environment and routine (e.g., milking).

Our results for both TS and FS cows showed little effect of 305ME yield but several effects of daily milk production. However, these effects were weak and not consistent across the lactation period. Furthermore, the effects of milk production on lying time are not consistent with other studies. Fregonesi and Leaver (2001, 2002) and Norring et al. (2011) showed that high-yielding cows had shorter lying times than cows with a low milk yield; these differences increased with reduced number of stalls and were linked to an increase in agonistic interactions (Fregonesi and Leaver, 2002). However, another study showed no effect of milk production on lying time (Nielsen et al., 2000). Our results may reflect housing conditions that limited competition in both tiestall and freestall barns studied, which favored high- and low-yielding cows resting.

Based on this study, due to the weak association of milk production with lying time, it may not be necessary to account for milk production during sampling on commercial farms, which is also practical because it may be difficult to gather milk production data before the farm visit. However, it is important to consider sampling based on both stage of lactation and parity to obtain lying time estimates representative of the herd. Our results showed that lying time varies greatly between cows due to individual differences that may not be controlled when sampling (i.e., stage of lactation, parity). Thus, it is important to ensure that a large enough sample of cows is chosen to account for likely individual differences. Ito et al. (2009) suggested sampling 30 lactating cows to evaluate lying time of a herd of 44 or more freestall cows with 90% accuracy.

Effect of Duration of the Time Sample on Lying Time

When recording at 1-min intervals, a 4-d sampling period is necessary to estimate lying time with at least 90% accuracy compared with the overall average based on 10 consecutive days. By comparison, a single-day sampling provided estimates with 60 to 81% accuracy compared with the overall average based on 10 d. To reach this level of accuracy, Ito et al. (2009)'s study, done on commercial freestall farms, needed only a 3-d sampling period, whereas a single-day sampling provided estimates with approximately 75% accuracy; however, the overall average in that case was based on 5 d. However, a shorter sampling period may be more practical for farm auditing systems. Based on

our results for TS and FS cows, we suggest that more research is needed for smaller farms to determine an accurate sample size before reducing the sample period to 1 d, so as not significantly reduce the accuracy of lying time estimates.

CONCLUSIONS

Automatic monitoring of lying time has potential as a herd-level measure of dairy cow welfare on commercial tiestall and freestall farms. However, cows differ greatly in lying time and it is necessary to sample cows based on their stage of lactation and parity, but probably not milk production level, to obtain a representative measure of the herd. Depending on the question that lying behavior is meant to inform, it may be necessary to evaluate lying time of the animals according to standards set for these factors. Especially for on-farm audits, targets for outcome-based measures need to take into account variation between animals. A 4-d sample accurately estimated daily lying time in tiestalls and freestalls taken over a 10-d period. If reducing the sample period to 1 d may be suitable for on-farm audits, more research is needed for smaller farms to determine the accurate sample size so as not to significantly decrease the accuracy of lying time estimates.

ACKNOWLEDGMENTS

We thank Agriculture and Agri-Food Canada and the Dairy Farmers of Canada for financial support, provided through the Dairy Research Cluster initiative. We also thank Rémy Mainguy (École Supérieure d'Angers, Angers, France) and Émilie Turmeau (AgroCampus Rennes, Rennes, France) for data handling, Jessica Zaffino and Janet Higginson (both from University of Guelph, Guelph, ON, Canada), Jean-Philippe Parent, Marianne Villettaz-Robichaud, and Jason Beukens (all from Agriculture and Agri-Food Canada, Agassiz, BC, Canada) for technical assistance. We thank Nelson Dinn and staff of the University of British Columbia's dairy research center (Agassiz, BC, Canada) as well as Joe Parkinson and Laura Wright of the University of Guelph's dairy research center (Elora, ON, Canada).

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