Milk yield affects time budget of dairy cows in tie-stalls

M. Norring,^{*1} A. Valros,^{*} and L. Munksgaard[†]

^{*}Research Centre for Animal Welfare, Faculty of Veterinary Medicine, University of Helsinki, FI-00014 Helsinki, Finland

[†]Faculty of Agricultural Sciences, Aarhus University, PO Box 50, DK-8830 Tjele, Denmark

ABSTRACT

Effective selection in breeding programs and improved management has increased the milk production per cow. However, the effects of the increased yield on behavior have not yet been clarified. We investigated the effect of milk yield on the time budget of 29 Finnish Ayrshire cows in the same stage of lactation kept in tie-stalls. The time spent lying, eating, ruminating, lying inactive without ruminating, and lying with the neck muscles relaxed, as well as the milk yield of primiparous and multiparous cows were recorded for 2 d. The effects of milk yield and parity on behavior were analyzed with mixed models. The mean milk yield was 38.3 kg (SD 7.8) per day. Higher-yielding cows spent more time ruminating while standing and less time lying than lower-yielding cows. The latency to lie inactive without ruminating after lying down decreased as milk yield increased and it was shorter in primiparous compared with multiparous cows. Multiparous cows ruminated more while lying than primiparous cows. High milk yield cows spent a shorter time lying and they fell asleep (lay with neck relaxed) sooner. The degree of daily milk yield was associated with modifications in behavior and cows with high milk production had less lying time even with free access to lie down in the tie-stall.

Key words: behavior, dairy cow, lying, milk yield

INTRODUCTION

Due to improved management, better nutrition, and effective selection for higher production, the daily milk yield of cows has increased considerably during recent decades (Rauw et al., 1998; Hansen, 2000). High-yield cows need more energy and consequently more time for consuming and processing food (Dado and Allen, 1994; Fregonesi and Leaver, 2002). Therefore, higher yield may be associated with shortage of time for resting (Munksgaard et al., 2005). The diurnal rhythm and distribution of behaviors during the day may also be

affected by the level of production. O'Connell et al. (2000) reported that cows with a higher genetic merit for milk yield had a higher grass intake, an increased bite rate, and spent more time ruminating than cows with a lower genetic merit when at pasture. However, Nielsen et al. (2000) observed no differences in the time budget of cows of different genetic merit for milk yield during the day in a freestall housing system. The time cows have available for eating and lying can also be affected by barn conditions, for instance crowding (Wierenga and Hopster, 1990; Leonard et al., 1996; Fregonesi et al., 2007) or a long waiting time for access to milking (Ketelaar-de Lauwere et al., 1996; Gomez and Cook, 2010).

Furthermore, some evidence indicates that the amount of milk in the udder can affect the amount of lying. Österman and Redbo (2001) reported that cows milked more frequently lay down for a longer time before the morning milking, and Overton et al. (2002) noted that the proportion of time spent lying decreased with time since milking. However, Tucker et al. (2007) found milking frequency to have no effect on the lying time in an experiment where peak lactation cows were milked either once or twice per day. It is not certain whether the decreased lying time of high-yield cows is mostly caused by a lack of time or discomfort of the udder due to the large volume of milk.

The daily lying time increases with increasing age and parity (Wierenga and Hopster, 1990; Chaplin and Munksgaard, 2001; Norring et al., 2008). Furthermore, lying time increases and eating time decreases as lactation proceeds (Chaplin et al., 2000; Fregonesi and Leaver, 2001; Bewley et al., 2010). This change in lying behavior may or may not be related to changes in milk yield throughout lactation. Despite the effect of stage of lactation on lying behavior, it is common to have cows of diverse lactation stages in research (Fregonesi and Leaver, 2001; Norring et al., 2008; Tucker et al., 2009). Furthermore, cows usually conceive during early lactation, and the proceeding gestation can affect their behavior and physiology (Nishida et al., 2004). Thus, further studies are needed to separate the effects of yield from the effects of the stage of lactation and the reproductive status of the cow on lying behavior.

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¹Corresponding author: Marianna.Norring@Helsinki.fi

In this experiment we used cows in a similar early stage of lactation to examine the effects of milk yield on their 24-h time budget, as well as their time budget before and after milking. In addition, we investigated the effect of milk yield on behaviors related to lying down, namely rumination and sleep.

MATERIALS AND METHODS

Animals, Housing, and Management

The time budget of 29 cows was observed for 2 d. We used Finnish Ayrshire cows in the eighth week of lactation with a mean of 58.3 d (SD 5.0) from parturition on the first day of observation. Fourteen of the cows were primiparous and the rest had calved 2.6 (SD 1.1) times. The cows weighed a mean of 617 kg (SD 65). The gait of the cows were scored visually according to Sprecher et al. (1997), and only cows with normal gait score and cows that were not in treatment for any disease were included in the experiment.

The cows were fed on grass silage ad libitum. Silage was produced from mixed timothy (*Phleum pratense*) and meadow fescue (*Festuca pratensis*)-based swards and ensiled with formic acid-based additive. Silage was added at 0500, 1200, 1400, 1500, and 1600 h according to the working schedules of the farm staff, and the left-over silage was removed each day at 1200 h. Silage was analyzed by electrometric titration and by near infrared reflectance spectroscopy (Moisio and Heikonen, 1989; Nousiainen et al., 2004). The average silage DM concentration was 27%; digestible organic matter in dry matter (D-value), 71%; concentration of CP, 15%; and NDF 50% in DM. Silage was well preserved, as indicated by the fermentation quality parameters.

In addition, all of the cows were fed on concentrate that was a mixture of commercial compound feed and protein concentrate (on average, 17% of total concentrate; Suomen Rehu, Espoo, Finland). Cows were fed on concentrate according to milk yield following the Finnish feeding recommendations, the daily amount ranging from 12.5 to 20.5 kg per cow. The daily total amount of concentrate of each cow was divided into 6 equal meals and offered to the animals approximately at 0500, 0800, 1100, 1400, 1700, and 2000 h. The data on the concentrate composition is based on the information given by the feed manufacturer. The DM content was 87% and both concentrates had 13 MJ of ME/kg. Compound feed contained on an air-dry basis 8% ash, 17% CP, 5% ether extract, and 8% crude fiber. Protein concentrate contained on an air-dry basis 8% ash, 30% CP, 7% ether extract, and 9% crude fiber.

Water was offered ad libitum from a water bowl. Cows were milked at 0600 and 1800 h in their tie-stalls.

Before and during the experiment, all the cows were housed in the same insulated barn in tie-stalls (170 × 121 cm) with rubber mats (2-cm thick; DeLaval, Tumba, Sweden) bedded with sawdust once per day. The cows were tethered to a neck bar. The barn was lit with natural and artificial light during the daytime and during the nighttime dimmer lightning was used.

Procedures and Observations

The experiment started at the beginning of October and ended at the beginning of January. When a cow reached her eighth week of lactation she was placed in 1 of the experimental stalls. The cows were allowed to adapt to the new location for 2 d. On the third and fourth day in the experimental stall, their behavior was video recorded (starting at 1200 h). If a cow was inseminated, the experiment was postponed for 1 d and the day of insemination was excluded (5 cows in total). Three regular adjacent tie-stalls, the middle of the row of tie-stalls, were used as experimental stalls. A total of 8 black and white cameras (Sanyo VCB-3372P, 3–8 mm wide-angle lens, 1/3-inch CCD matrix; Sanyo, Watford, UK) were used to observe the cows' jaw movements. Three main cameras were located at 2 to 4 m of distance and 2 m above the entrance of each stall, focusing on the cows' heads. Three additional cameras were located at the rear end of each stall. Also, 2 additional cameras were located at the entrance of each stall above the main cameras to record adjacent stalls. Time-lapse (Panasonic AG-6730; Panasonic Corp., Secaucus, NJ) recording with 24-h time mode was used, and the pictures from all cameras were fed to 1 tape using a multiplexer (Robot; Tyco, Princeton, NJ). The amount of milk was measured at every milking using milk recording standards; the accuracy achieved was 200 g (Tru-Test Ltd., Pakuranga, New Zealand).

The posture (lying or standing) and head and jaw movements in relation to eating, rumination, and resting behaviors were recorded (Table 1). The behaviors and postures were recorded using continuous observation (Observer; Noldus Information Technology, Wageningen, the Netherlands). The behaviors were analyzed with an accuracy of 1 min while observing the videos. The bout of 1 behavior was considered to end as soon as another behavior was recorded. The behaviors used in the analysis were lying, eating, ruminating, lying while ruminating, standing while ruminating, lying inactive without ruminating, lying with the neck relaxed, and lying with other activities.

Statistical Methods

All cows received the same management, and relationships between parity, milk yield and behavioral

Table 1. Postures and behaviors observed and the definitions of observations¹

Item	Definition
Posture	
Lying	Rump on the floor
Standing	Standing on 4 feet
Behavior	
Eating	Taking silage into the mouth and jaw moving, or muzzle in contact with silage and moving
Ruminating	Jaw moving, not taking silage into the mouth
Inactive without ruminating	Jaw not moving, head not moving, head up
Lying with the neck relaxed	Jaw not moving, neck relaxed, and head in contact with the feeding table in front of the cow, or reversed along her body
Other activities	All other behaviors of the head not mentioned above; for example, head moving actively, drinking, eating concentrate, licking, social behavior, and pressing the muzzle toward equipment

¹Lying inactive without ruminating and lying with the neck relaxed were observed to estimate the resting and sleeping time.

variables were analyzed using the SPSS (v. 15.0) statistical program (SPSS Inc., Chicago, IL). Statistical significance is indicated by *P*-values and *F*-test values with degrees of freedom as subscripts.

24-h Time Budget. To estimate the effects of milk yield and parity on the 24-h time budget, a mixed model was used. The duration of the behaviors and the number of bouts of behavior per day were used as response variables. Individual cows were considered as the experimental units. Day was the repeated effect and cow was the subject in the repeated statement. Parity (divided into 2 classes: primiparous heifers and multiparous cows at parity 2 and above) was inserted as a fixed factor. Daily milk yield was used as a continuous variable and it was inserted as a regression variable into the model. The initial model showed the yield $\times$ parity interaction to be nonsignificant, and the interaction term was, therefore, excluded from the final model. The degrees of freedom were corrected with the Satterthwaite method. The compound symmetry covariance structure provided the best model fit.

Effects of Yield and Parity on Behavior Before and After Milking. To be able to analyze the effect of yield and parity on time budget (during each 4-h period) before and after milking, a mixed model was used. Data from before morning milking, after morning milking, before evening milking, and after evening milking were analyzed separately. The percentage of time allocated to different behaviors (lying, eating, ruminating, standing, and not eating, lying while ruminating, standing while ruminating, lying inactive without ruminating, lying with the neck relaxed, lying with other activities) during the 4-h periods was analyzed. Day was inserted into the model as a repeated effect and the animal as the subject in the repeated statement. Parity was included as a fixed factor. Milk yield at either the evening or morning milking was included as a regression variable. The compound symmetry covariance structure provided the best model fit.

Lying Down Latency After Milking. To evaluate the effect of milk yield and parity on latency from the end of milking until lying down, a mixed model was used. The morning and evening milkings were analyzed separately. Day was inserted into the model as a repeated effect and cow as the subject in the repeated statement. Parity was inserted as a fixed factor. Milk yield was included as a regression variable. The compound symmetry covariance structure provided the best model fit.

Lying Bout Structure. Latency to initiation of different behaviors after the commencement of a lying bout was analyzed with a mixed model. Latency to rumination, other activities, lying inactive without ruminating, lying with the neck relaxed, and the combination of either of the 2 last behaviors was analyzed. Parity was inserted as a fixed factor. Milk yield (2-d average) was inserted as a regression variable. Due to technical difficulties lying bouts at midnight and midday are unrepresented in this data. The average latency was calculated from all of the lying bouts. One average latency per behavior was determined for each cow.

RESULTS

The mean milk yield was 19.5 kg (SD 4.2) in the morning and 18.8 kg (4.1) in the evening, and the mean daily yield was 38.3 kg (SD 7.8), with a minimum of 28 kg and a maximum of 63 kg.

24-h Time Budget

Higher-yielding cows spent less time lying and a longer time ruminating while standing (Figure 1). In addition, higher-yield cows were ruminating while standing more frequently ($F_{1,44} = 5.3$, $P = 0.026$; slope = 0.1 bout/kg, 95% CI = 0.0 to 0.6 bouts). Yield did not affect the total duration of rumination ($F_{1,38} = 0.2$, $P = 0.67$; slope = 0.8 min/kg, 95% CI = -2.9 to 4.6 min),

Figure 1. Duration of lying and ruminating while standing in relation to milk yield. All of the cows were in their eighth week of lactation. Ruminating while standing: $F_{1,50} = 12.1$, $P = 0.001$, slope = 7.1 min/kg, 95% CI = 3.0 to 11.2 min; lying: $F_{1,50} = 6.1$, $P = 0.017$, slope = -10.4 min/kg, 95% CI = -18.9 to -2.0 min; results of F -test are shown, with degrees of freedom as subscripts.

rumination while lying ($F_{1,47} = 3.4$, $P = 0.07$; slope = -5.2 min/kg, 95% CI = -11.0 to 0.5 min), eating ($F_{1,42} = 2.2$, $P = 0.14$; slope = 1.7 min/kg, 95% CI = -0.6 to 4.1 min), other activities ($F_{1,46} = 0.2$, $P = 0.70$; slope = -1.1 min/kg, 95% CI = -6.7 to 4.5 min), lying with other activities ($F_{1,51} = 3.4$, $P = 0.07$; slope = -3.3 min/kg, 95% CI = -6.8 to 0.2 min), lying inactive without ruminating ($F_{1,52} = 2.2$, $P = 0.14$; slope = -3.4 min/kg, 95% CI = -8.0 to 1.2 min), lying with the

neck relaxed ($F_{1,41} = 0.2$, $P = 0.68$; slope = 0.5 min/kg, 95% CI = -1.8 to 2.7 min), or the number of bouts of the behaviors ($P > 0.05$).

Effect of Yield on Behavior Before and After Milking

Before morning milking (0200 to 0600 h), higher-yield cows spent a lower percentage of time lying and a higher percentage of the time eating and standing without eating than lower-yield cows (Table 2). After morning milking (0600 to 1000 h) higher-yield animals spent a lower percentage of time lying and larger percentage of time eating.

Before evening milking (1400 to 1800 h), the duration of lying was unaffected by milk yield. After evening milking (1800 to 2200 h), higher-yield cows spent a lower percentage of time lying than lower-yield cows and a higher proportion of their time was spent standing without eating. High-yield cows also ruminated a lower percentage of the time while lying and ruminated a larger percentage of the time while standing than did lower-yield cows.

Lying Down Latency After Milking

The milk yield did not affect the latency to lie down after milking. In addition, parity had no effect on the lying down latency after milking ($P > 0.05$).

Table 2. Allocation of time (expressed as percentage) to different behaviors 4 h before and after milking¹

Behavior	Time of day			
	0200 to 0600 h	0600 to 1000 h	1400 to 1800 h	1800 to 2200 h
Lying	38 ⁻²	60 ⁻³	22	50 ⁻⁴
Eating	13 ⁺⁵	11 ⁺⁶	23	17
Standing without eating ⁷	49 ⁺⁸	29	55	33 ⁺⁹
Ruminating	34	24	19	24
Lying while ruminating	—	18	—	15 ⁻¹⁰
Standing while ruminating ¹¹	—	6	—	9 ⁺¹²
Lying inactive without ruminating	11	22	9	19
Lying with the neck relaxed	6	8	3	8
Other activities	35	35	46	32

¹The effect of milk yield on behavior is indicated by + and -: + = positive association between behavior and yield; - = negative association between behavior and yield. Each period is analyzed separately. Statistical significance is indicated by P -values and F -test values with degrees of freedom as subscripts.

² $F_{1,52} = 8.8$, $P = 0.005$; slope = -2.1%/kg, 95% CI = -3.6 to -0.7%.

³ $F_{1,33} = 5.3$, $P = 0.027$; slope = -1.3%/kg, 95% CI = -2.4 to -0.2%.

⁴ $F_{1,50} = 7.4$, $P = 0.009$; slope = -2.0%/kg, 95% CI = -3.5 to -0.5%.

⁵ $F_{1,49} = 6.2$, $P = 0.016$; slope = 0.6%/kg, 95% CI = 0.1 to 1.1%.

⁶ $F_{1,34} = 4.8$, $P = 0.034$; slope = 0.4%/kg, 95% CI = 0.0 to 0.8%.

⁷Percent of standing time minus percent of eating time.

⁸ $F_{1,52} = 4.8$, $P = 0.033$; slope = 1.5%/kg, 95% CI = 0.1 to 2.9%.

⁹ $F_{1,51} = 8.3$, $P = 0.006$; slope = 1.7%/kg, 95% CI = 0.5 to 2.9%.

¹⁰ $F_{1,54} = 4.8$, $P = 0.032$; slope = -1.1%/kg, 95% CI = -2.1 to -0.1%.

¹¹Percent of ruminating time minus percent of lying while ruminating time.

¹² $F_{1,54} = 4.5$, $P = 0.038$; slope = 0.8%/kg, 95% CI = -0.0 to 1.5%.

Table 3. Number of bouts with certain behavior at the beginning of a lying bout

Behavior	Frequency of lying bouts
Eating	35
Ruminating	223
Other activities	633
Inactive without ruminating	7
Neck relaxed	0
Total	899

Lying Bout Structure

High-yield cows had a shorter latency to lie inactive without ruminating ($F_{1,26} = 5.8$, $P = 0.023$; slope = -0.5 min/kg, 95% CI = -1.0 to -0.1 min) and lie with the neck relaxed ($F_{1,26} = 10.9$, $P = 0.003$; slope = -0.8 min/kg, 95% CI = -1.2 to -0.3 min), or either of these behaviors ($F_{1,26} = 6.2$, $P = 0.020$; slope = -0.5 min/kg, 95% CI = -0.8 to -0.1 min). However, milk yield did not affect the latency to ruminate ($P = 0.59$) or the latency to perform other activities ($P = 0.83$). In the majority of lying bouts, the first behavior a cow performed was lying with other activities and lying with the neck relaxed never initiated a lying bout (Table 3).

Parity

The latency to lie inactive without ruminating or lie with the neck relaxed after lying down was shorter in primiparous than multiparous cows (Table 4). The multiparous cows ruminated overall for a longer time while lying than did primiparous cows (Table 5). When the time periods were tested, multiparous cows were observed to spend more time ruminating after morning milking than did primiparous cows (28 ± 2 vs. $19 \pm 2\%$; $F_{1,29} = 7.3$, $P = 0.011$). Multiparous cows ruminated more while lying after milking than primiparous cows (morning: 23 ± 3 vs. $13 \pm 3\%$; $F_{1,30} = 6.0$, $P = 0.020$; evening: 20 ± 3 vs. $10 \pm 3\%$; $F_{1,54} = 4.7$, $P = 0.036$).

DISCUSSION

In the present study, the higher-yielding cows spent less time lying and more time ruminating while stand-

ing. Our results suggest that factors other than time constraints due to duration of eating affect the lying behavior of high-yield cows. With increasing yield, the latency to lying with the neck relaxed decreased, suggesting that high-yield cows had higher motivation to sleep than low-yield cows.

High-yield cows at their peak lactation spent less time per day lying than low-yield cows, in agreement with Hasegawa et al. (1993). Previous results suggest that the total daily lying time is shorter in early lactation than in late lactation, when the milk yield is usually lower (Chaplin and Munksgaard, 2001; Fregonesi and Leaver, 2001; Olmos et al., 2009; Bewley et al., 2010).

The decrease in the total daily lying time in combination with no effect on eating time with increasing milk yield suggests that other factors than time constraints due to eating, contributed to the decrease. Udder discomfort before milking is one explanation suggested by Österman and Redbo (2001) and Overton et al. (2002). In addition, Tucker et al. (2007) found an increase in udder firmness scores when the milking frequency was changed from twice per day to once per day. In our study, the cows spent less time lying before the morning milking, but not before the evening milking; and with increasing yield, the cows also spent less time lying after milking both in the morning and in the evening. Therefore, discomfort before milking can only partly explain the results, and the results suggest that other factors than udder discomfort or time constraints affect the duration of lying.

The time cows spent lying, lying with neck relaxed, eating, and ruminating was comparable with earlier results (Dado and Allen, 1994; Jensen et al., 2005; Rushen et al., 2007; Ito et al., 2009). In our study, high-yield cows also spent more time ruminating while standing. High-yield cows might have been in need of more time to ruminate because of their higher level of food intake, but in our study they did not increase the total eating or rumination time. The time spent eating silage by high-yield cows did not increase, possibly because the energy requirements of high-yielding cows were met by feeding them more concentrates.

Table 4. The effect of parity on the mean $\pm$ SE latency in minutes to various behaviors from the beginning of lying bouts

Latency to	Primiparous, min	Multiparous, min
Rumination	10 ± 2	10 ± 2
Other activities	3 ± 1	6 ± 1
Lying inactive without ruminating	3 ± 2^a	13 ± 2^b
Lying with the neck relaxed	12 ± 2^a	22 ± 2^b
Lying inactive either not ruminating or with neck relaxed	3 ± 2^a	12 ± 2^b

^{a,b}Different superscript letters within a row indicate differences between parity classes ($P < 0.05$).

Table 5. Twenty-four-hour time budget of primiparous and multiparous dairy cows kept in tie-stalls (mean minutes $\pm$ SE)

Minutes per 24 h	Primiparous, n = 14	Multiparous, n = 15
Lying	579 $\pm$ 48	680 $\pm$ 48
Eating	226 $\pm$ 12	208 $\pm$ 12
Ruminating	369 $\pm$ 19	427 $\pm$ 19
Lying while ruminating	160 $\pm$ 32 ^a	282 $\pm$ 31 ^b
Standing while ruminating	215 $\pm$ 28	139 $\pm$ 27
Other activities	505 $\pm$ 31	518 $\pm$ 30
Lying with other activities	96 $\pm$ 21	126 $\pm$ 20
Lying inactive without ruminating	201 $\pm$ 29	192 $\pm$ 28
Lying with the neck relaxed	107 $\pm$ 12	77 $\pm$ 12

^{a,b}Different superscript letters within a row indicate differences between parity classes ($P = 0.019$).

According to Ruckebusch (1975) and Hänninen et al. (2008), lying with the neck muscles relaxed and remaining inactive without ruminating are signs of sleep. In the present study, cows started their lying bouts with active lying behaviors, and lying bouts were never initiated by lying with the neck relaxed. However, lying inactive without ruminating took place earlier than ruminating within an average lying bout. The latency to lying with the neck relaxed or inactive without ruminating within a lying bout decreased with increasing yield. This suggests that high-yield cows might have been more motivated to sleep than low-yield cows, and therefore fell asleep faster (Tobler, 1995; McKenna et al., 2008). Ruckebusch (1974) observed that cows slept more following sleep deprivation. Several authors have reported that cows, after few hours of forced standing, spend a longer time lying than cows with free access to lie down (Metz, 1985; Cooper et al., 2007, 2008) indicating that the motivation to rest builds up after few hours of lying deprivation.

We found that higher-parity cows ruminated more while lying compared with primiparous heifers. Contrary to our results, Phillips and Leaver (1986) observed that primiparous cows reclined while ruminating more than multiparous cows in pasture. In our study, primiparous cows assumed lying with relaxed neck or lying inactive without ruminating sooner after lying down than did multiparous cows. Furthermore, heifers could have been more motivated to sleep than multiparous cows because of their younger age and because they were still growing (Hänninen et al., 2003), and therefore fell asleep sooner.

In conclusion, high-yield cows spent less time lying down and more time ruminating while standing than low-yielding cows managed in tie-stalls. Primiparous cows and cows with a higher yield had a shorter latency to lying with neck relaxed after lying down than multiparous and low-yielding cows. As the degree of milk yield was associated with changes in behavior, the consequences of these effects for welfare should be fur-

ther studied. Cows in the tie-stall had 24 h unrestricted access to resting, yet the highest-producing cows might have experienced inadequate lying time. The decrease in lying time may be even more pronounced in loose housing systems where cows have to walk between lying and feeding areas and wait for access to milking, especially when competition exists for access to feeding and resting areas.

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