

Published in final edited form as:

J Dairy Sci. 2008 December ; 91(12): 4552–4559. doi:10.3168/jds.2008-1048.

Lameness, Activity Time-Budgets, and Estrus Expression in Dairy Cattle

S. L. Walker¹, R. F. Smith, J. E. Routly, D. N. Jones, M. J. Morris, and H. Dobson²

Department of Veterinary Clinical Science, Faculty of Veterinary Science, University of Liverpool, Leahurst, Neston, Wirral CH64 7TE, United Kingdom

Abstract

The aim of the present study was to identify specific behavioral patterns that contribute to diminished estrus expression in lame cows. Behavioral scan and focal sampling were used to examine the effect of lameness on daily activity budgets, sexual behavior, feeding activities, and body condition score. A total of 59 milking cows (51.8 ± 1.4 d postpartum) were monitored on a commercial dairy farm for 5 d following estrus synchronization. Overall, lame cows ($n = 39$) spent proportionately less time elevated on their feet and more time lying down compared with nonlame cows ($n = 20$). This included lame cows spending less time walking or standing. Overall, the total proportion of scans in which an estrous behavior was observed was very small but tended to be smaller for lame compared with nonlame cows. Throughout a day, lame cows displayed a lower proportion of estrous behaviors in the early morning. Lameness did not affect durations of drinking, grazing, or ruminating, or how these behavioral states fluctuated throughout the day. Similarly, rumination chewing rates were the same for lame and nonlame cows, and there was no association between lameness and dominance/displacement while feeding at a feed-fence. Lame cows did, however, have a slower bite rate at pasture and had a lower body condition score. Lame cows were also nearer the rear of the herd, both as they left the field and when entering the milking parlor. In conclusion, lame cows have longer lying times and spend less time standing, walking, and expressing an estrous behavior. Lame cows also have a lower bite rate at pasture and are more likely to be of lower body condition score.

Keywords

bite rate; rumination chewing rate; social order; lameness

INTRODUCTION

Lameness is a chronically painful and stressful condition associated with poor reproductive performance and reduced estrus intensity in dairy cows (Collick et al., 1989; Whay et al., 1997; Walker et al., 2008). There are many physiological, psychological, behavioral, and environmental factors that can influence the intensity of estrus expression in cattle (Orihuela, 2000). For example, stress is known to have a negative impact on reproductive hormones from the hypothalamus-pituitary-ovarian axis (Moberg, 1985; Liptrap, 1993; Dobson et al., 2003). Indeed, an earlier study revealed low progesterone exposure before estrus in chronically stressed lame cows that was related to the low intensity of sexual behaviors during estrus (Walker et al., 2008). Therefore, similar to other ruminants, previous

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²Corresponding author: hdobson@liv.ac.uk.

¹Present address: North of England Zoological Society, Chester Zoo, Upton by Chester, CH2 1LH, United Kingdom.

progesterone concentrations appear crucial to the intensity of sexual behaviors (Fabre-Nys and Martin, 1991). The overarching objective of the current study was to identify general behavioral activities that may contribute to the already established diminished estrus expression in lame cows (Walker et al., 2008).

The reduced estrus expression in lame cows may be caused by physical limitations of the stressor itself (i.e., lameness), as estrus in cattle includes the overt expression of behaviors such as increased walking/restlessness with a sexually active group, sniffing the vulva of fellow herdmates, flehmen, chin resting, and mounting behavior (Allrich, 1994; Van Vliet and Van Eerdenburg, 1996). Indeed, we have already established that the decreased estrus intensity in lame cows involves a reduced frequency of primary (i.e., mounting behavior) and secondary (i.e., sniffing and chin resting) estrous behaviors (Walker et al., 2008). However, based on a subjective three-hourly behavioral scoring system, lame cows were just as “restless” as nonlame cows during estrus (“restless” is a state of behavior subjectively assessing excessive walking, bunting, playful). This suggests that the decreased intensity of estrous behavior is not the result of hampered movement but rather lame cows dedicating a smaller proportion of their daily activities to expressing estrous behavior. Previous studies in pregnant and nonpregnant cows have considered the effect of lameness on general activity time-budgets, including the proportion of time spent lying, standing, or walking (Hassall et al., 1993; Singh et al., 1993; Galindo and Broom, 2002). However, whether lame and nonlame cows differ in these behavioral states specifically during estrus needs clarifying. Therefore, the first aim of the present study was to determine if there are differences in the daily activity time-budgets in lame and nonlame cows during estrus. As first-lactation animals are under considerable additional stress (both nutritional and hierarchical), these cows were excluded from the present study.

Poor nutrition or the loss of body reserves (negative energy balance) results in reduced reproductive efficiency and can negatively affect estrus expression (Orihuela, 2000; Lucy, 2003; Ferguson, 2005). Increasing levels of nutrient intake and cows that maintain body condition are associated with shorter intervals to the first postpartum estrus (Butler, 2000). Negative energy balance affects gonadotropin pulsatility and ovarian steroid synthesis (Butler, 2000), both of which could have a negative impact on estrus expression (Allrich, 1994; Caraty et al., 2002). Therefore, although cause and effect will not be determined, a second aim of the present study was to investigate the association between body condition score and lameness. For similar reasons, a third aim of the present study was to examine the feeding activities of lame and nonlame cows on pasture, including bite and rumination rates and the proportion of time dedicated to these behavioral states. Fourth, in tandem with the feeding studies, we monitored agonistic interactions while feeding inside (routinely used to describe dominance in competitive feed situations in cattle; Galindo and Broom, 2000) to determine whether lame cows had less access to supplementary feed. Lameness is a significant welfare issue, which is costly for the dairy industry and to the individual cow (Greenough et al., 1997). Risk factors for conditions causing lameness in dairy cows are walking order from the field and milking order (Sauter-Louis et al., 2004); therefore, although cause and effect will not be determined, the order cows leave the field and the order in which they are milked was examined to further highlight the imposition that lameness has on the well-being of dairy cattle.

In summary, we aimed to examine behavioral reasons for the previously determined reductions in estrus intensity and poor body condition in lame cows, by determining the impact of lameness on daily time budgets, the duration of estrus behaviors, and feeding and social activities. To facilitate frequent simultaneous behavioral observations in lame and nonlame cows, ovarian follicular phases were synchronized using a hormonal regimen that did not involve administration of exogenous progesterone to avoid disrupting the

endogenous progesterone milieu. A regimen of GnRH followed 7 d later by PGF_{2α} was used. Characteristics of prostaglandin (PG)-induced estrus are not different from those occurring spontaneously (Walker et al., 1996).

MATERIALS AND METHODS

Experimental Design, Animals, Feeding, and Housing

The study was conducted on postpartum Holstein-Friesian cows (n = 59) on a UK commercial dairy farm comprising approximately 200 year-round calving cows. The average rolling milk yield per cow in the herd was 8,500 L/yr. Animals were at pasture (seasonal ryegrass, Italian ryegrass, and white clover) for the duration of the summer study with additional access to a TMR inside at a feed-fence after milking twice a day. The cows ranged between 3 and 10 yr of age. The median parity and mean days postpartum of the study cows were 4 (range 2–10) and 51.8 ± 1.4 d (range 30–75 d), respectively. Cows were selected based on lameness score (see below) and days postpartum. Ovarian follicular phases were synchronized in 5 groups of approximately 12 animals (including at least 4 nonlame cows/group) between May and September 2005 (temperatures ranged from 5 to 28°C) using a 100-μg i.m. injection of a GnRH analog (buserelin, 2.5 mL of Receptal, Intervet Ltd., Bucks., UK) followed by a single 500-μg i.m. injection of PGF_{2α} analog (cloprostenol, 2 mL, Estru-mate, Schering-Plough Animal Health, Uxbridge, UK) 7 d later. All studies were conducted in accordance with requirements of the UK Animal (Scientific Procedures) Act of 1986, and were approved by the University of Liverpool Animal Welfare Committee.

Lameness and Body Condition Scoring

Individuals were scored for lameness (score 1–3) by the same experienced observer once a week for 4 wk before the commencement of the study. The scores were based on gait and posture while walking and standing in a concrete walkway, using methods adapted from Sprecher et al. (1997) and summarized in Table 1. Prior clinical treatments for lameness were recorded and continued following normal farm practice (e.g., regular foot-trimming, skin/hoof dusting with antibiotic powder). Retrospectively, 95% of individuals had the same lameness score throughout or one score that was ±1 for the duration of the study. Any cow with an average score of 2 was considered to be lame, and animals were grouped as either nonlame (score of 1; n = 20) or lame (score of 2 or 3; n = 39). Concurrently, animals were scored for body condition on a scale of 1 to 5 using an established method (Chamberlain and Wilkinson, 1996). Only 3 cows had an average BCS of 3 or 4; therefore, animals were grouped as low BCS (score 1; thin; n = 10) or moderate BCS (score 2–4; n = 49).

Activity Time-Budget and Estrous Behaviors

Behavioral scan samples (Martin and Bateson, 1986) every 15 min were made daily for 5 d following PG injection. Milking took place twice daily at approximately 0630 and 1600 h, and scans were carried out 3 times a day around milking: early morning (0300 to approximately 0600 h), midday (approximately 0900 to 1600 h), and evening (approximately 1800 to 0000 h). To allow for different time spans, data were expressed as percentage activity per period (see later). Scans were conducted with the aid of binoculars while the cows were in the field; small flashlights were used to aid nighttime observations and did not alter any behavior. To ease identification of the cows, identity labels made from waterproof paper (The Waterbook, Stowmarket, UK) and black waterproof pen were attached above each shoulder with Kamar glue (Kamar Products Inc., Steamboat Springs, CO). The 8 behavioral states recorded are listed in Table 2. An individual was considered to be in a state of estrus when one of the following signs of estrus was observed: mounting the rear or head of another cow, receiving mounts but not standing, standing to be mounted,

chin resting on another cow, sniffing the vulva of another cow, or flehmen. Detailed results concerning estrus intensity have been reported elsewhere (Walker et al., 2008); the data obtained in the present study concern only the proportional amount of time an estrous behavior was observed.

Bite and Rumination Chewing Rates

Focal behavioral observations (Martin and Bateson, 1986) were conducted during the afternoon for 3 d in the follicular phase following PG injection. Grazing cows were observed for 1 min 10 times/d for bite rate, which was expressed as the number of bites/minute recorded during continuous 1-min periods ($n = 30$ observations/follicular phase per cow). Intermittent breaks in bite rate >5 s were not considered as continuous and such data were discarded. Bite rates were monitored randomly between cows so that no 2 observations were made consecutively for one cow. Similarly, rumination chewing rate was recorded in a randomized fashion. Rumination chewing rate was also observed 10 times/d and calculated as the number of chews per rumination bout (each bout was determined as the time between the first and last of a series of eructations; $n = 30$ bouts observed/cow).

Social Order

Social order observations were performed in 2 situations: as cows 1) left the field for milking and 2) entered the milking parlor. Chi-square analysis revealed that there was no association between month (1–5) and the number of lame and nonlame cows; that is, there were similar proportions of lame and nonlame cows in each month ($P = 0.714$). Therefore, order (on a scale of 0–1) was standardized across studies by calculating the position (first to last) of a cow's order in relation to other cows within the group divided by the total number of cows in that group. An average leaving-field or being-milked order was calculated for each cow. Consequently, cows with a high order value were at the rear of the group. Observations ($n = 10$ /cow) for leaving-field order were carried out once a day for 1 wk before PG and for 5 d after PG by an observer standing at end of the track as the cows passed to the milking parlor. Observations ($n = 17$ /cow) for milking order were collected by an observer standing inside the milking parlor once a day for 1 wk before PG as well as twice a day for 5 d after PG.

Index of Agonistic Interactions

Focal behavioral observations for agonistic interactions while feeding were conducted for a 3-d period following PG. Cows were observed while eating an “extra-buffer” ration at an inside feed-fence (grooved concrete flooring) following morning milking for twelve 2-min intervals per day ($n = 36$ observations/cow). The 2-min observations were randomized over the 1-h feeding period so no 2 observations were made consecutively in one cow. This randomization allowed study cows to move and reposition between other herdmates. Using methods adapted from Galindo and Broom (2000), interactions were recorded as either a “win” (a study cow challenged another cow and successfully displaced that cow, or she herself was challenged and was not displaced from feeding; i.e., more access to feed) or a “loss” (a study cow challenged another cow and was not successful at displacing that cow, or she herself was the recipient of a challenge and was displaced from feeding). The index of agonistic interactions (scale 0–1) was calculated as the total number of times a cow won divided by the total number of interactions recorded (total wins + losses) for the same cow. Based on the calculated index value, cows were retrospectively given an index of low (0 – 0.49), medium (0.5 – 0.69), or high (0.7 – 1.0).

Data Analysis

All data are presented as mean \pm standard error of the means and were analyzed using Minitab 14 software (Minitab Inc., State College, PA). General linear model ANOVA and pair-wise post hoc comparisons were made with Tukey's 95% test. Statistical differences were reported when $P < 0.05$, with a tendency being considered when $0.05 < P < 0.10$. Model residuals were plotted to check for normality and for a lack of systematic trend compared with fitted data.

Total time spent in a behavioral state in the early morning/midday/evening periods or in total was calculated as the number of times a behavioral state was observed divided by the total number of observations recorded for each cow and is presented as the proportion of scans (%). Data were then normalized using arcsine-square root transformation (Martin and Bateson, 1986). Total times spent in the different behavioral states between lame and nonlame cows were compared with GLM ANOVA. The model included the fixed factors of lameness, month (1–5) and the interaction between lameness and month. Comparisons of time spent in the different behavioral states in different periods (early morning, midday, and evening) and lameness were analyzed with GLM ANOVA with the fixed factors of lameness, month, period and the interaction of lameness and period, and lameness and month.

The GLM ANOVA was used to compare bite/rumination chewing rates and leaving-field/being-milked order between lame and nonlame cows. The model included the fixed factors of lameness and month and cow ID with lameness and month also nested within cow ID (as each cow was only present in one category within each factor) and the interaction of lameness and month.

Associations within the following groups were examined using Chi-square tests: lameness (nonlame/lame), index of agonistic interactions (high/medium/low), BCS (low/moderate), and estrus (yes/no). Pearson correlations were used to assess the relationship between an individual's leaving-field and being-milked order.

RESULTS

Activity Time-Budgets

In both lame and nonlame cows, the greatest proportion of time was spent grazing (~34%), followed by lying with or without ruminating (approximately 29 and 18%, respectively), with <10% time spent in each of the remaining behavioral states (Table 2). Throughout, lame and nonlame cows spent similar proportions of time grazing, drinking, or ruminating (standing or lying), but lame cows spent less time elevated on their feet (includes standing with or without ruminating, drinking, estrous behavior, grazing and walking) and lay down for longer (includes lying with or without rumination; Table 2).

In both lame and nonlame cows, from early morning to midday to evening, the proportion of time spent grazing or drinking increased, whereas time for totals of ruminating, lying, or standing decreased; walking was unaffected by period of day (Figure 1). In the GLM ANOVA model including period of day, the total proportion of time spent lying was greater for lame cows; total proportion of time spent standing and walking were again lower.

Estrous Behavior

Similar proportions of lame and nonlame cows were seen in estrus (lame 22/39 and nonlame 15/20; $P = 0.162$). The total proportion of scans in which an estrous behavior was observed was very small (<3%) but tended to be lower in lame cows (Table 2). Throughout the early

morning, midday, and evening, lameness reduced the period for which an estrous behavior was displayed but nonlame cows expressed an estrous behavior more frequently only in the early morning (Figure 1G).

Social Order and Index of Agonistic Interactions

Lame cows left the field later and entered the milking parlor later (Table 3). There was a high correlation within all the 59 cows between average order out of the field and average milking order ($r^2 = 0.704$; $P = 0.001$). There was no association between index of agonistic interactions (high/medium/low) while feeding at a feed fence and the occurrence of lameness (lame $n = 3/23/13$; nonlame $n = 3/11/6$ cows, respectively; $P = 0.691$).

BCS and Bite and Rumination Chewing Rates

More lame cows had a low BCS (10/39 lame, 0/20 nonlame; $P = 0.013$) and lame cows had a lower bite rate while grazing (lame 53.1 ± 0.3 , nonlame 54.9 ± 0.4 bites/min; $P = 0.001$). There was also a gradual increase in bite rate over the summer months ($P = 0.001$; Figure 2), except in September. Conversely, there was no difference in rumination chewing rate between groups (lame 59.4 ± 0.3 , nonlame 59.0 ± 0.4 chews/rumination bout; $P = 0.117$).

DISCUSSION

Lame cows spent more time lying during estrus compared with nonlame cows. Additionally, lame cows had a low BCS and a lower bite rate while grazing.

In more detail, the current study demonstrated that lame cows spend less time elevated on their feet, due in part to spending less time standing and walking compared with nonlame cows. Contrary to this, (Hassall et al., 1993) reported that lame and nonlame cows at pasture did not differ in the amount of time spent standing or walking. The difference between these studies is interesting as cows in the current study were observed only during estrus. This suggests that normally, lame cows walk and stand as much as nonlame cows; however, during estrus, when nonlame cows walk more, lame cows suppress this behavior.

As the proportions of time spent grazing or drinking were unaltered in the current study, the deficits observed in the total time budget of lame cows (i.e., decreased proportion of time standing, walking, and performing an estrous behavior) were counterbalanced by increased lying time as also observed by Hassall et al. (1993). Therefore, lame cows may be moving with the sexually active group but lie down more and require more frequent rests (i.e., more standing around and less walking). As the number of cows participating in a sexually active group increases, so does the chance to display a behavioral sign of estrus resulting in increased estrus intensity (Roelofs et al., 2005). Thus, lame cows, resting more frequently, have less opportunity to express an estrous behavior, all of which require standing. Collectively, this implies that the low-intensity estrus in lame cows is caused in part by a decreased proportion of time standing and walking because of increased lying time.

The present study demonstrated that lame cows tend to spend less time expressing estrous behaviors compared with nonlame cows. Considering that observation of an estrous behavior only accounted for a very small proportion of the total time budget (2.8% in nonlame cows), there was a large reduction (of approximately 36%) in the time committed by lame cows to expressing an estrous behavior. Interestingly, in a parallel study on the same cows quantifying estrus intensity using a weighted scoring system, lame cows scored fewer total points compared with nonlame cows ($1,417 \pm 206$ points vs. $2,260 \pm 307$ points), equating to an overall reduction of approximately 37% in estrus intensity (Walker et al., 2009).

Lameness also affected the daily pattern of estrous behavior because nonlame cows expressed estrus more in the early morning compared with lame cows. Although some studies suggest no variation in estrus during the day (Esslemont and Bryant, 1976; Xu et al., 1998), estrous behaviors have been reported to be more frequent during the nocturnal period and early morning (Hurnik et al., 1975; Van Vliet and Van Eerdenburg, 1996). The difference between studies is probably related to difference in farm management practices rather than a true diurnal rhythm. Even so, the difference in the present study suggests that lameness has a negative effect on estrous behaviors in the early morning on this particular farm, a key time when the herdsman was watching for estrus before artificial insemination.

The drive to show estrous behavior appears to be deferred in favor of lying down. Perhaps the evolutionary instinct to reproduce (including expressing estrus) is delayed, possibly in the hope that the situation will improve in the future (i.e., the pain of lameness will be overcome). These changes could be brought about hormonally, as we have already shown that lame cows have lower progesterone concentrations before estrus (Walker et al., 2008). A pheromonal mechanism may also be involved as distinct estrous behaviors are affected (Walker et al., 2008). Despite the pain, lame cows are involved in some sexual behavior but they minimize the frequency of their own mounting and the duration of being attractive to others (attempts at being mounted). In addition, they exhibit fewer chin rests; this is a behavior that may be a means of soliciting mounting from herdmates, or an activity to test whether it is worth expending energy or enduring pain to mount others. Finally, lame cows may be less “attractive” to others; they may emit a lesser quantity/quality of sexual pheromones or even stress-related pheromones. Indeed, there is evidence to indicate that cattle perceive an increased state of stress in herdmates by olfactory cues (Boissy et al., 1998).

Another potential contributing factor to the reduced expression of sexual behaviors could be related to the low BCS of lame cows observed in the current study. Reduced estrus intensity in lame cows is associated with a lower progesterone concentration before estrus (Walker et al., 2008). Similar to acute stress, nutritional stress or severe negative energy balance affects gonadotropin pulsatility and ovarian steroid synthesis (Butler, 2000). However, not all cows cope with negative energy balance after calving, and as suggested several years ago, any additional stressor (such as lameness) that disrupts this knife-edge balance will ultimately lead to impaired reproductive function including poor expression of estrus (Dobson and Smith, 2000).

The results from the present study demonstrate that the poor body condition observed in lame cows was not due to decreased grazing time; in fact, the majority of feeding activities were largely unaffected by lameness, as also seen by Cook et al. (2004). This is in contrast to Almeida et al. (2006) who found marked decreases in ruminating and eating times in a very small group of severely lame cows not in estrus ($n = 8$). In the present study, lame cows in estrus grazed, ruminated, and drank for similar proportions of time compared with nonlame cows, concurring with other non-estrus studies (Hassall et al., 1993; Singh et al., 1993). Similarly, lameness had no effect on the fluctuating patterns of grazing, ruminating, and drinking throughout the day. Furthermore, lame cows in estrus were no more likely to be displaced while feeding at a feed-fence or spend less total time feeding, similar to animals not in estrus (Singh et al., 1993; Galindo and Broom, 2002). However, the poor body condition of lame cows in estrus could be explained by the 3% reduction in bite rate while at pasture in agreement with Hassall et al. (1993) who, in addition to a shorter grazing time, also reported a lower bite rate in lame pregnant and nonpregnant cows.

Another possible contributor to a low BCS could be related to management practice. In agreement with other studies, lame cows were near the rear of the group as they left the field

later and entered the milking parlor later (Hassall et al., 1993; Sauter-Louis et al., 2004). Cows that were milked later (i.e., lame cows) spent less time eating the high-energy-dense food at the feed-fence before the whole group was sent out to pasture. Therefore, although cause and effect were not proven in the current study, the impact of a slower bite rate and reduced time feeding at the feed-fence may explain the poor body condition of lame cows.

The reason for the increasing bite rate in both lame and nonlame cows throughout the year is not clear, except that the nutritional quality of commercial grass species declines from May through September in temperate climates (Pontes et al., 2007). Each month represents different groups of cows; thus, the reversal of results in September could be explained by between-animal variability.

CONCLUSIONS

Reduced estrus expression in lame cows can be explained by altered time budgets compared with non-lame cows. Lame cows dedicate less time to standing and walking as a consequence of lying down more, thus decreasing the opportunity to express sexual behavior. The low BCS of lame cows is not due to a reduction in grazing time but is related to lower bite rates while grazing and possibly less supplemental feed intake after milking. These results highlight the additional behavioral and physiological costs plus the detriment to welfare that lameness imposes on dairy cattle beyond the obvious pain involved.

Acknowledgments

The authors wish to thank farm staff for their assistance and support with the project. The authors are grateful for technical assistance from Hilary Pursell, University of Liverpool. Scholarships (to SLW) were provided by Natural Sciences and Engineering Research Council of Canada (NSERC), Universities UK and University of Liverpool. MJM is a Wellcome Trust Clinical Fellow.

REFERENCES

- Allrich RD. Endocrine and neural control of estrus in dairy cows. *J. Dairy Sci.* 1994; 77:2738–2744. [PubMed: 7814742]
- Almeida PE, Weber PSD, Burton JL, Zanella AJ. Depressed DHEA and increased sickness response behaviours in lame cows with inflammatory foot lesions. *Domest. Anim. Endocrinol.* 2008; 34:89–99. [PubMed: 17229542]
- Boissy A, Terlouw C, Le Neindre P. Presence of cues from stressed conspecifics increases reactivity to aversive events in cattle: Evidence for the existence of alarm substances in urine. *Physiol. Behav.* 1998; 63:489–495. [PubMed: 9523888]
- Butler WR. Nutritional interactions with reproductive performance in dairy cattle. *Anim. Reprod. Sci.* 2000; 60–61:449–457. [PubMed: 22422014]
- Caraty A, Delaleu B, Chesneau D, Fabre-Nys C. Sequential role of e2 and GnRH for the expression of estrous behavior in ewes. *Endocrinology.* 2002; 143:139–145. [PubMed: 11751602]
- Chamberlain, AT.; Wilkinson, JM. *Feeding the Dairy Cow.* Chalcombe Publications; Lincoln, UK: 1996.
- Collick DW, Ward WR, Dobson H. Associations between types of lameness and fertility. *Vet. Rec.* 1989; 125:103–106. [PubMed: 2773242]
- Cook NB, Bennett TB, Nordlund KV. Effect of free stall surface on daily activity patterns in dairy cows with relevance to lameness prevalence. *J. Dairy Sci.* 2004; 87:2912–2922. [PubMed: 15375052]
- Dobson H, Ghuman S, Prabhakar S, Smith R. A conceptual model of the influence of stress on female reproduction. *Reproduction.* 2003; 125:151–163. [PubMed: 12578529]
- Dobson H, Smith RF. What is stress, and how does it affect reproduction? *Anim. Reprod. Sci.* 2000; 60–61:743–752. [PubMed: 22422014]

- Esslemont RJ, Bryant MJ. Oestrous behaviour in a herd of dairy cows. *Vet. Rec.* 1976; 99:472–475. [PubMed: 1034995]
- Fabre-Nys C, Martin GB. Roles of progesterone and oestradiol in determining the temporal sequence and quantitative expression of sexual receptivity and the preovulatory LH surge in the ewe. *J. Endocrinol.* 1991; 130:367–379. [PubMed: 1940713]
- Ferguson JD. Nutrition and reproduction in dairy herds. *Vet. Clin. North Am. Food Anim. Pract.* 2005; 21:325–347. [PubMed: 15955433]
- Galindo F, Broom DM. The relationships between social behaviour of dairy cows and the occurrence of lameness in three herds. *Res. Vet. Sci.* 2000; 69:75–79. [PubMed: 10924398]
- Galindo F, Broom DM. The effects of lameness on social and individual behavior of dairy cows. *J. Appl. Anim. Welf. Sci.* 2002; 5:193–201. [PubMed: 12578740]
- Greenough, PR.; Weaver, DA.; Broom, DM.; Esslemont, RJ.; Galindo, FA. Basic concepts of bovine lameness. In: Greenough, PR.; Weaver, AD., editors. *Lameness in Cattle*. W. B. Saunders; Philadelphia, PA: 1997. p. 3-13.
- Hassall SA, Ward WR, Murray RD. Effects of lameness on the behaviour of cows during the summer. *Vet. Rec.* 1993; 132:578–580. [PubMed: 8337801]
- Hurnik JF, King GJ, Robertson HA. Estrus behavior and estrus detection in postpartum dairy cows. *Can. J. Anim. Sci.* 1975; 55:473–474.
- Liptrap RM. Stress and reproduction in domestic animals. *Ann. N. Y. Acad. Sci.* 1993; 697:275–284. [PubMed: 8257018]
- Lucy MC. Mechanisms linking nutrition and reproduction in postpartum cows. *Reprod. Suppl.* 2003; 61:415–427. [PubMed: 14635952]
- Martin, P.; Bateson, P. *Measuring Behaviour*. Cambridge University Press; Cambridge, UK: 1986.
- Moberg, GP. Influence of stress on reproduction: Measure of well-being. In: Moberg, GP., editor. *Animal Stress*. American Physiological Society; Bethesda, MD: 1985. p. 245-267.
- Orihuela A. Some factors affecting the behavioural manifestation of oestrus in cattle: A review. *Appl. Anim. Behav. Sci.* 2000; 70:1–16. [PubMed: 10986419]
- Pontes LS, Carrere P, Andueza D, Louault F, Soussana JF. Seasonal productivity and nutritive value of temperate grasses found in semi-natural pastures in Europe: Responses to cutting frequency and N supply. *Grass Forage Sci.* 2007; 62:485–496.
- Roelofs JB, van Eerdenburg FJ, Soede NM, Kemp B. Various behavioral signs of estrous and their relationship with time of ovulation in dairy cattle. *Theriogenology.* 2005; 63:1366–1377. [PubMed: 15725444]
- Sauter-Louis, CM.; Chesterton, RN.; Pfeiffer, DU. Behavioural characteristics of dairy cows with lameness in Taranaki. Vol. 52. *New Zealand; N. Z. Vet. J.*: 2004. p. 103-108.
- Singh SS, Ward WR, Lautenbach K, Murray RD. Behaviour of lame and normal dairy cows in cubicles and in a straw yard. *Vet. Rec.* 1993; 133:204–208. [PubMed: 8236723]
- Sprecher DJ, Hostetler DE, Kaneene JB. A lameness scoring system that uses posture and gait to predict dairy cattle reproductive performance. *Theriogenology.* 1997; 47:1179–1187. [PubMed: 16728067]
- Van Vliet JH, Van Eerdenburg FJCM. Sexual activities and oestrus detection in lactating Holstein cows. *Appl. Anim. Behav. Sci.* 1996; 50:57–69.
- Walker SL, Smith RF, Jones DN, Routly JE, Dobson H. Chronic stress, hormone profiles and estrus intensity in dairy cattle. *Horm. Behav.* 2008; 53:493–501. [PubMed: 18206887]
- Walker SL, Smith RF, Jones DN, Routly JE, Morris MJ, Dobson H. The effect of a chronic stressor, lameness, on detailed sexual behaviour and hormonal profiles in milk and plasma of dairy cattle. *Reprod. Domest. Anim.* 2009 doi:10.1111/j.1439-0531.2008.01263.x.
- Walker WL, Nebel RL, McGilliard ML. Time of ovulation relative to mounting activity in dairy cattle. *J. Dairy Sci.* 1996; 79:1555–1561. [PubMed: 8899521]
- Whay HR, Waterman AE, Webster AJ. Associations between locomotion, claw lesions and nociceptive threshold in dairy heifers during the peri-partum period. *Vet. J.* 1997; 154:155–161. [PubMed: 9308402]

Xu ZZ, McKnight DJ, Vishwanath R, Pitt CJ, Burton LJ. Estrus detection using radiotelemetry or visual observation and tail painting for dairy cows on pasture. *J. Dairy Sci.* 1998; 81:2890–2896. [PubMed: 9839231]

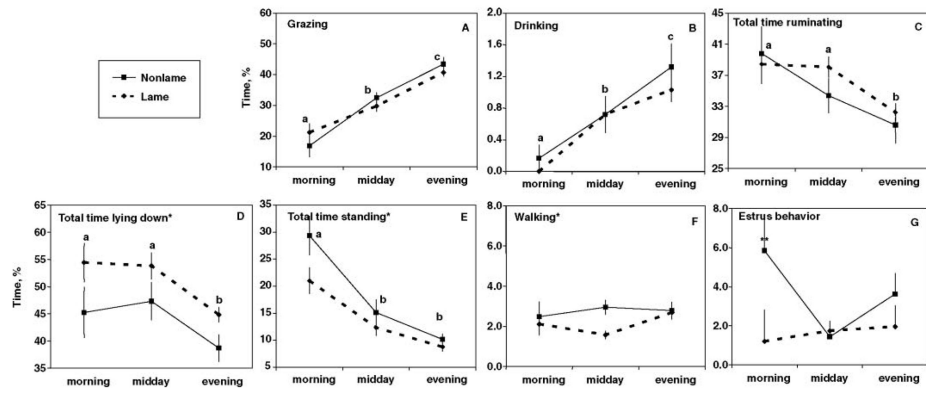


Figure 1.

Daily time budgets for lame ($n = 39$) or nonlame ($n = 20$) during the morning, midday, and evening, including proportion of scan samples (%) spent A) grazing, B) drinking, C) ruminating (total includes standing or lying ruminating), D) lying down (total includes with or without ruminating), E) standing (total includes with or without ruminating), F) walking, and G) observation of an estrus behavior. *Indicates behavioral state where lameness was an explanatory variable in the statistical model ($P < 0.05$); abc indicates differences between the morning, midday, and evening periods for all cows (lame and nonlame; $P < 0.05$); ** indicates the difference between lame and nonlame cows at different periods ($P < 0.05$; only seen in estrus behavior).

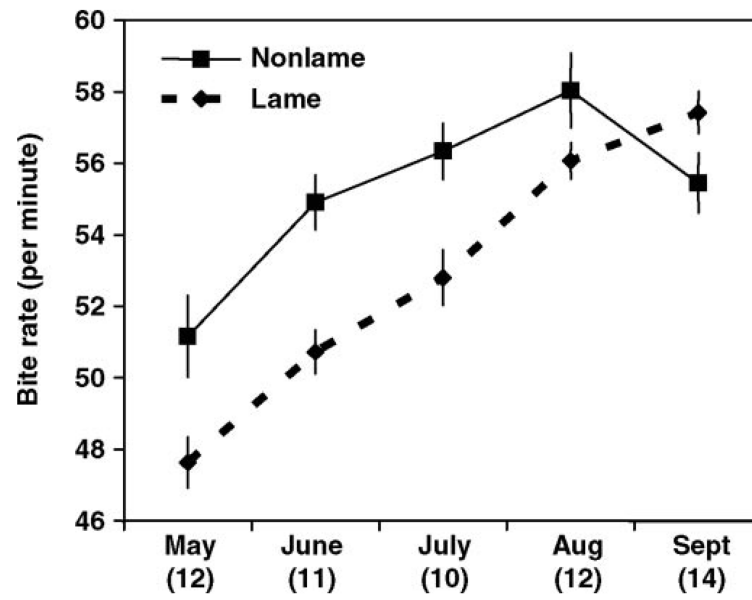


Figure 2. Bite rate (per minute) for lame ($n = 39$) and nonlame ($n = 20$) cows while grazing during the summer months. Numbers in parentheses below months indicate total number of animal studies in each month. Lame versus nonlame: $P = 0.001$.

Table 1Lameness scoring scale¹

Lameness score		Description		
		While standing	While walking	Gait
1	Nonlame	Level back posture	Level back posture	Normal
2	Mildly lame	Level back posture	Arched back	Normal to short striding
3–5	Moderately to severely lame	Arched posture	Arched back	Takes one step at a time; reluctant to bear weight on one or more limbs/feet

¹This scale has been modified from a previously described 5-point scale (Sprecher et al., 1997) in which the above scores of 1, 2, and 3 are comparable to the scores of 1, 2, and 3–5 on the Sprecher 5-point scale, respectively. In the present study, any cow with an average score ≥ 2 was considered to be lame, and animals were grouped as either nonlame (score of 1) or lame (score of 2–5).

Table 2

The activity time-budget of lame (n = 39) and nonlame (n = 20) dairy cows following estrus synchronization presented as the total percentage of scans (%) in which a behavioral state was observed

Activity	Lame	Nonlame	Difference, ¹ %	P-value ²
Grazing	33.5 ± 1.0	35.5 ± 1.5	—	0.388
Lying down (with ruminating)	30.8 ± 1.0	27.1 ± 1.5	+3.7	0.042
Lying down (without ruminating)	19.3 ± 1.2	16.7 ± 1.5	+2.6	0.049
Standing (with ruminating)	5.0 ± 0.5	6.3 ± 1.0	-1.3	0.080
Standing (without ruminating)	6.8 ± 0.5	7.9 ± 0.4	-1.1	0.083
Walking	2.1 ± 0.2	2.8 ± 0.2	-0.7	0.007
Expressing an estrous behavior	1.8 ± 0.4	2.8 ± 0.6	-1.0	0.090
Drinking	0.8 ± 0.1	0.9 ± 0.2	—	0.885
Total: Elevated on feet ³	49.9 ± 1.3	56.2 ± 1.7	-6.3	0.003
Total: Lying down (with and without ruminating)	50.1 ± 1.3	43.8 ± 1.7	+6.3	0.003
Total: Standing (with and without ruminating)	11.8 ± 0.8	14.2 ± 1.1	-2.4	0.036
Total: Ruminating (lying and standing)	35.8 ± 0.9	33.4 ± 1.9	—	0.270

¹Difference is calculated as the percentage difference in behavioral states between lame and nonlame cows.

²Statistical differences are shown in bold (GLM ANOVA followed by Tukey's pairwise comparison).

³Includes standing with or without ruminating, grazing, drinking, walking, and expressing an estrous behavior.

Table 3Order of lame (n = 39) or nonlame (n = 20) cows leaving the field (field) or entering the parlor (milking)¹

Order ²	Lame	Nonlame	P-value
Field order	0.58 ± 0.02	0.46 ± 0.02	0.001
Milking order	0.58 ± 0.01	0.47 ± 0.02	0.001

¹Data are presented as average order (scale 0–1) ± SEM.

²Order (on a scale of 0–1) was standardized across studies by calculating the position (first to last) of a cow's order in relation to other cows within the group. A higher order represents a position nearer to the rear of the group.