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Daily Activity Measures and Milk Yield Immediately Before and After a Fertile Estrus

J.S. Stevenson

Summary

The objective was to characterize changes in milk yield and other physical measures during a 7-day periestrual period encompassing estrus (day 0) and insemination. Lactating dairy cows milked thrice daily were fitted with CowManager SensOor ear tags capable of assessing real time eating, rumination, resting, high activity (estrus), ear-surface temperature, and providing heat alerts. Daily milk was unchanged during the periestrual period. Daily ear-surface temperature was greater during days 1 to 3 compared with day 0. Daily rumination and resting times reached nadirs on day 0, with decreases occurring 48 hours before estrus. Both rumination and resting times increased by 25 or 81% on the day after estrus, respectively. In contrast, daily eating time was greatest on the day of estrus compared with 3 days before and after estrus. High activity increased by 97% during 48 hours before estrus, peaked at estrus, and then decreased to a constant level during days 1 through 3. In conclusion, resting and rumination activity decreased to daily nadirs while eating and high activity peaked on the day of estrus. Fertile estrus was associated with 12% greater high activity, 11% less resting time, and 6% less rumination time.

Introduction

Identifying cows in estrus is a critical component of a successful insemination program. Detection programs must have the ability to detect correctly all cows in estrus (sensitivity) and differentiate cows in estrus from those not truly in estrus (specificity). Identifying various physical or behavioral and chemical signals that accurately detect estrus has been the objective of much research. Technologies that provide the solution for detection problems should provide: (1) continuous (24 hours/day) surveillance of the cow; (2) accurate and automatic identification of cows in estrus; (3) operation for the productive lifetime of the cow; (4) minimized labor requirements; and (5) accuracy in identifying the appropriate physiologic or behavioral events that correlate largely with ovulation.

Visual detection of behavioral estrus plays an important role in overall reproductive management programs in most U.S. dairies despite the widespread adoption of fixed time ovulation-synchronization programs. Furthermore, other physiological changes associated with visual standing-to-be-mounted behavior include changes in vaginal cytology and temperature, pH, electrical resistance of vaginal mucus and genital tissue, physical activity, body temperature, blood flow, pheromones, hormones, milk yield, and feed intake.

Cows spend considerably more time walking and less time resting and eating when in estrus. The average increase in activity at the time of estrus, assessed by pedometry, was 393% when cows were housed in free stall barns. New technologies are available to detect various physiological measures, including increased physical activity, a commonly measured correlate of estrus. With the advancement of technology, pedometers are being replaced with more sophisticated automated activity monitors that employ accelerometers (assesses movement in three dimensions) to quantify increased physical activity associated with estrus. Activity monitoring systems have increased recording and reporting of activity from a few times daily to continuous real-time monitoring.

Although milk yield may decrease as much as 0.25 to 5 lb during the day of estrus, no correlation between estrus expression and milk yield has been reported. Metabolic clearance of steroid hormones (i.e., estradiol) related to elevated daily feed intake and milk yield may reduce behavioral manifestation of estrus. In a study of 5,883 estrus events, each 1 kg (2.2 lb) increase in milk yield was associated with a 1.6% decrease in walking activity at estrus.

The hypothesis of this study was that physical activities and changes in milk yield during the periestrual period are associated with estrus and subsequent pregnancy outcome. The objective was to characterize daily changes in milk yield, rumination, eating, resting, high activity, and ear-surface temperature during a 7-day period encompassing the day of estrus.

Experimental Procedures

Cows in the Kansas State University Dairy Teaching and Research Center were housed in free stalls with overhead roofs and fed a total mixed diet twice or thrice (summer) daily calculated to meet nutrient requirements for lactating dairy cows producing 50 kg of 3.5% milk. The diet consisted of alfalfa hay, corn silage, triticale-sweet clover silage, soybean meal, whole cottonseed, ground corn grain, corn-gluten feed, vitamins, and minerals. Cows were milked thrice daily and milk weights were recorded automatically in PC-DART software (Dairy Record Management System, Raleigh, NC).

Cows were fit with CowManager SensOor ear tags (Agis, Harmelen, Netherlands) to monitor estrus (high activity) in addition to ancillary measures of ear-surface temperature, eating, rumination, and resting (inactive) times. Estrual events were predicted by the ear tag accelerometer data according to proprietary software algorithms. Cows (n = 386) were inseminated the same day as "heat alerts" were produced from the software. Each cow was considered to be a unique experimental unit during the 3-yr study for each estrus event that occurred. Pregnancy was determined by transrectal ultrasonography at 32 ± 3 days after insemination.

All statistical analyses were performed by using SAS v. 9.4 software (SAS Institute, Cary, NC). A mixed model procedure was applied to account for correlated repeated measures assessed from each experimental unit. The statistical model included pregnancy status on day 32 (pregnant vs. not pregnant), parity (primiparous vs. multiparous), day relative to estrus (day -3 through day +3), all 2-way and 3-way interactions of pregnancy status, parity, and day, in addition to the fixed effect of season of estrus (cold [October through April] and hot [May through September]) and DIM at estrus (covariate). Least square means (LSM) ± SEM are reported. In all cases, statistical significance of effects was set as $P < 0.05$, with tendencies as $0.05 < P < 0.10$.

Results and Discussion

Milk Yield

Pregnancy status on day 32 was not associated with any change in milk yield during the periestrual period (Figure 1). Daily milk yield was 10.6 kg (23.4 lb) greater ($P < 0.001$) in multiparous cows (52.3 [115.3 lb] ± 0.6 kg) than in primiparous cows (41.7 [91.9 lb] ± 0.6 kg) during the 7 days that encompassed estrus. Daily milk yield means only tended ($P = 0.10$) to differ with a decrease of 1.3 (2.0 lb) ± 0.7 kg (2.7%) of milk yield on day 1 compared with the day of estrus. Season did not affect ($P = 0.42$) milk yield.

Ear-Surface Temperature

Daily ear-surface temperature differed ($P < 0.001$) during the periestrual period, with greater daily temperatures on day -1 (25.43 ± 0.3°C), day 1 (25.69 ± 0.3°C), and day 2 (25.58 ± 0.3°C) after estrus; all of which were greater ($P < 0.01$) than that observed on the day of estrus (day 0 = 25.0 ± 0.3°C, Figure 2). Although no associations of either pregnancy status or parity were observed with ear-surface temperature, ear-surface temperature decreased ($P < 0.05$) by 1.7% during the last 24 hours before estrus. After estrus, ear-surface temperatures increased ($P < 0.05$) by 2.8% on day 1. As expected, cows had greater ($P < 0.001$) ear-surface temperatures during hotter months than cows during colder months (30.6 ± 0.3 vs. 20.3 ± 0.3°C), respectively. On the day of estrus, cows producing ≤ 46 kg (101.4 lb) of milk had lower ear-surface temperatures than cows producing more than 46 kg (25.2 ± 0.5 vs. 26.6 ± 0.5°C), respectively.

Eating

Eating time during the periestrual period was greater ($P < 0.001$) on the day of estrus compared with the 3 days before and 3 days after estrus (Figure 3). Cows subsequently diagnosed not pregnant had marginally greater ($P < 0.10$) eating times on all days except for days 0 and 1, ranging from 5.1 to 12.8 more minutes per cow per day. In contrast, pregnant cows had marginally greater ($P < 0.10$) eating times on days 0 and 1 ranging from 5.1 to 6.7 more minutes per cow per day. Eating time increased by 20.2% (46.0 ± 6.1 minutes) during the 24 hours before the day of estrus and then decreased by 22.3% (61.1 ± 6.1 minutes) on day 1.

Primiparous cows spent more time eating than multiparous cows (252 ± 6 vs. 197 ± 6 minutes/day), respectively, during the periestrual period. As expected, cows spent less ($P < 0.001$) time eating during hotter months than during colder months (208 ± 7 vs. 240 ± 5 minutes/day), respectively. For every 1-kg (2.2 lb) increase in milk yield on the day of estrus, eating time decreased ($P = 0.03$) marginally by 1.5 ± 0.7 minutes.

Rumination

Rumination time varied ($P < 0.001$) across the periestrual period. Rumination decreased ($P < 0.01$) by 22% (118 ± 8 minutes/day) during 48 hours before estrus, with the smallest rumination time per day occurring on the day of estrus compared with the

3 days that preceded and followed (Figure 4). During 48 hours after estrus, rumination time increased ($P < 0.05$) by 24% (102 ± 5 minutes).

Multiparous cows spent more ($P < 0.001$) time ruminating than primiparous cows (567 ± 3 vs. 519 ± 4 minutes/day), while daily rumination time was greater ($P < 0.001$) during hotter than colder months (534 ± 7 vs. 505 ± 6 minutes/day), respectively. On the day of estrus, for each 1-kg (2.2 lb) increase in milk yield, rumination time increased ($P < 0.001$) by 3.2 ± 0.7 minutes. Cows producing more than 46 kg (101.4 lb) of milk on the day of estrus spent more ($P = 0.04$) time ruminating than cows producing ≤ 46 kg of milk (448 ± 13 vs. 411 ±13 minutes/day), respectively.

Resting

Resting or inactive time was least ($P < 0.01$) on the day of estrus compared with the 3 days that preceded and followed the day of estrus (Figure 5). Resting time decreased ($P < 0.05$) by 40% (129 ± 5 minutes) during 48 hours before the day of estrus. During 48 hours after estrus, resting time increased ($P < 0.05$) by 81% (157 ± 5 minutes). Future pregnancy status was associated with more ($P = 0.002$) resting time. Pregnant compared with nonpregnant cows rested more ($P = 0.002$) every day of the periestrual period, except on the day of estrus when resting time was at a nadir (Figure 5). Multiparous cows spent more ($P < 0.001$) time resting than primiparous cows (325 ± 5 vs. 298 ± 5 minutes/day). Resting time was greatest during colder than hotter months of the year (346 ± 4 vs. 277 ± 5 minutes/day), respectively.

High Activity

As expected, the greatest ($P < 0.01$) high activity was detected on the day of estrus compared with the 3 days that preceded and followed the day of estrus (Figure 6). Daily high activity increased ($P < 0.01$) by 97% (183 ± 5 minutes/day) during 48 hours before estrus, and then decreased ($P < 0.01$) by 52% (192 ± 5 minutes) during the 24 hours after the day of estrus. Pregnant compared with nonpregnant cows had 12% (42 ± 5 minutes) greater ($P < 0.05$) high activity on the day of estrus, whereas the reverse was evident on all other days.

Primiparous cows were more ($P < 0.001$) active than multiparous cows (227 ± 5 vs. 190 ± 5 minutes/day), respectively, but high activity did not differ ($P = 0.14$) between colder than hotter months (211 ± 5 vs. 205 ± 5 minutes/day), respectively. When daily high activity was regressed on milk yield on the day of estrus, for every 1-kg (2.2 lb) increase in milk yield, high activity decreased ($P = 0.002$) by 2.5 ± 0.8 minutes. Furthermore, cows producing ≤ 46 kg (101.4 lb) of milk tended ($P = 0.09$) to have greater high activity on the day of estrus than cows producing more than 46 kg of milk (412 ± 14 vs. 380 ± 14 minutes/day), respectively.

Correlations and Regression Coefficients

Simple correlations among physical measures, ear-surface temperature, and milk yield are shown in Table 1. On the day of estrus, milk yield was correlated positively ($P < 0.001$) with rumination time and tended ($P = 0.07$) to be related to eating and resting time, but was negatively correlated ($P < 0.001$) with high activity. Ear-surface temperature was negatively correlated ($P < 0.001$) with eating and resting time, but was positively ($P < 0.001$) related to rumination time. Eating time was negatively ($P < 0.001$) associated with rumination and resting time ($P < 0.001$), but positively correlated ($P < 0.001$) with high activity. High activity was negatively correlated ($P < 0.001$) with both rumination and resting times, while rumination and resting were positively associated ($P < 0.001$).

Multiple regression of high activity on combined measures of rumination, eating, resting, ear-surface temperature, and milk yield on the day of estrus produced significant negative regression coefficients except for milk (Table 1; $R^2 = 0.90$). The best-fit model excluded milk, but retained all other measures on the day of estrus and produced the same R^2 (0.90).

General Discussion

Changes in milk characteristics occur during the estrous cycle including fat, protein, casein, lactose and fatty acid profiles, urea, somatic cells, freezing point, pH, and homogenization index, of which, several components peak on the day of estrus. On the day of estrus, milk yield was negatively correlated with high activity in the present study.

Cows with greater milk yields have reduced blood estradiol at estrus and shorter and less intense periods of sexual receptivity (estrus) than cows with lesser milk yield. More rapid metabolic clearance of estradiol in lactating cows likely limits duration and intensity of estrus, which is consistent with less walking activity at estrus in cows with greater milk yields. The present study is consistent with those observations with a modest 2.5 fewer minutes of high activity at estrus per 1-kg (2.2 lb) increase in milk yield and a difference of 32 minutes more of high activity for cows producing ≤ 46 kg (101.4 lb) of milk on the day of estrus.

Activity, including actual steps or walking time, peaked on the day of estrus and the increase in walking activity at estrus was related to pregnancy rate in other studies. In agreement with earlier reports, high activity on the day of estrus was 12% greater in cows diagnosed pregnant on day 32 than in nonpregnant cows in the present study. Others have reported that cows are 2.3 to 6 times more active at the time of estrus compared with non-estrus cows. Furthermore, older cows have less peak heat activity and less intensity of estrus compared with younger cows. Activity increased markedly during 48 hours before estrus in the present study, indicating it is a reliable predictor of estrus.

An earlier study reported that estrual behaviors have an ordered sequence based on visual observations beginning with sniffing the vulva, chin resting on other cows, mounting other cows but not accepting a mount, in addition to passive behaviors of being sniffed, and finally standing to be mounted. All of these latter behaviors were observed in the reverse order after the last standing event. The motion activity profile in the latter study increased at the onset of exploratory behaviors, with greatest activity values occurring during the period of standing-to-be-mounted, which peaked before the last standing event. Activity correlates positively with most behavioral symptoms including standing estrus, mounting behavior, chin-resting, sniffing, butting, and the occurrence of other cows displaying estrus.

Rumination was positively correlated with resting times, but both were negatively associated with high activity assessed on the day of estrus in the present study. Both rumination and resting decreased during 48 hours before reaching nadirs on the day of estrus and increased to baseline levels on the next day. On the day of estrus, resting time averaged less than 3.5 hours, whereas post-estrus daily resting ranged from 6 to 7 hours per day in the present study.

Eating time on the day of estrus was surprisingly greater than on the days that preceded or followed estrus (averaging approximately 3.6 hours per day). Eating time was greater by 4.5 hours on the day of estrus in the present study, with primiparous cows spending more time eating than multiparous cows. Consistent with these observations in another study using the same sensor, researchers reported that eating time was greater for cows in estrus compared with the 14 days preceding estrus. Furthermore, with this same sensor, feeding and ruminating activities were well correlated with visual observations.

Post-estrus ear-surface temperature was greater during the 3 days after the day of estrus in the present study and was negatively associated with eating and resting times. Using the same ear tag sensor as in the present study, another group detected a significant increase in ear temperature during estrus, but they reported that their readings were inconsistent. Vaginal temperature decreased during 2 days before estrus and the elevation in vaginal temperature on the day of estrus was short-lived (approximately 9 hours). Increases in body temperature, body core temperature (increase of 0.2 to 0.3°C), and milk temperature were observed on the day of estrus. Because ear-surface temperature determined by the sensor in the present study was nearly perfectly correlated with ambient temperature ($r = 0.99$), the increase observed in ear-surface temperature during the 3 days after estrus may be a delayed response that was partly affected by ambient temperature and other external factors. Ear-surface temperature may have less potential for predicting estrus compared with other activities such as step count, lying bouts, lying time, rumination, feeding time, and reticulorumen temperature.

Conclusions

Resting and rumination activity decreased to daily nadirs while eating and high activity peaked on the day of estrus, and these activities differed among cows that conceive or do not conceive at estrus. Fertile estrus was associated with 12% greater high activity, 11% less resting time, and 6% less rumination time. Measures of daily rumination, eating, and resting times, and ear-surface temperature on the day of estrus accounted for nearly all (90%) of the variation in high activity minutes on the day of estrus.

Table 1. Correlations among measures and model regression coefficients of high activity regressed on eating, rumination, resting, ear-surface temperature, and daily milk yield for cows on the day of estrus

	Simple correlations					
Item	Ear-surface temperature	Eating	Rumination	Resting	High activity	Regression coefficients[1]
Daily milk	-0.06	-0.11[a]	+0.26[b]	+0.11[a]	-0.21[b]	-0.10 ± 0.25
Ear temperature		-0.18[b]	+0.18[b]	-0.22[b]	-0.07	-3.55 ± 0.39[b]
Eating			-0.73[b]	-0.35[b]	+0.26[b]	-0.71 ± 0.04[b]
Rumination				+0.37[b]	-0.66[b]	-0.89 ± 0.03[b]
Resting					-0.73[b]	0.93 ± 0.03[b]

[a] Differ from zero ($P < 0.10$).
[b] Differ from zero ($P < 0.001$).
[1] The model included daily milk, ear-surface temperature, eating, rumination, and resting ($R^2 = 0.90$). Intercept = 1,260 ± 27.

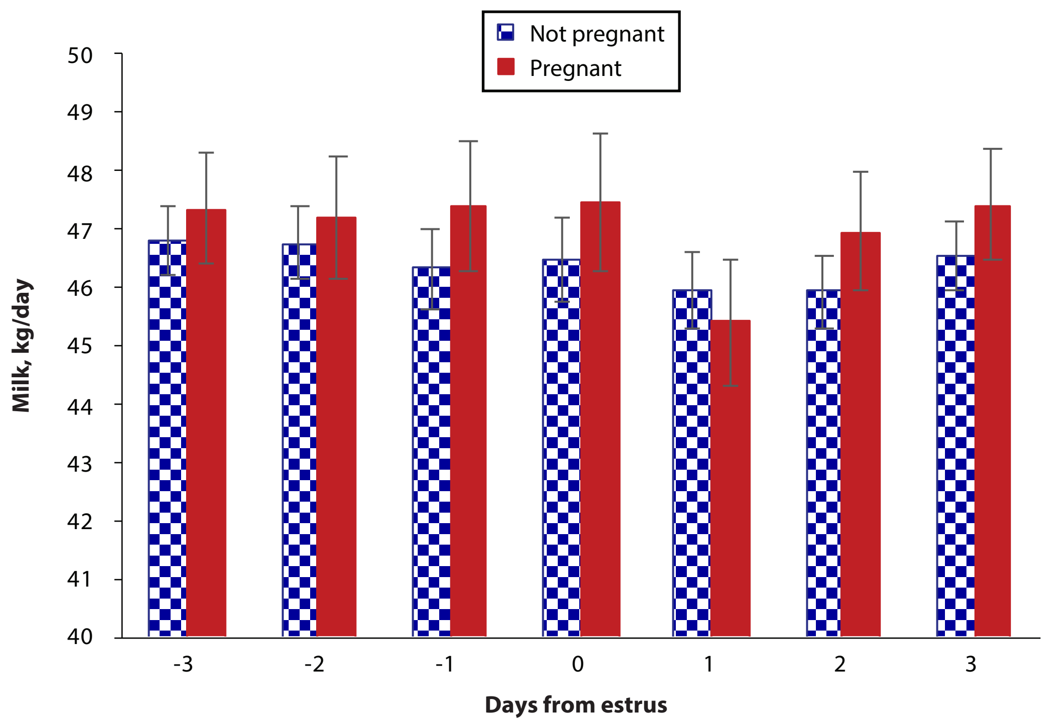

Figure 1. Daily milk yield (LSM ± SEM) during 3 days before estrus (day 0), estrus, and 3 days after estrus in cows that were diagnosed pregnant (n = 179) or not pregnant (n = 62). Pregnancy status was determined on day 32 ± 3 after estrus and insemination.

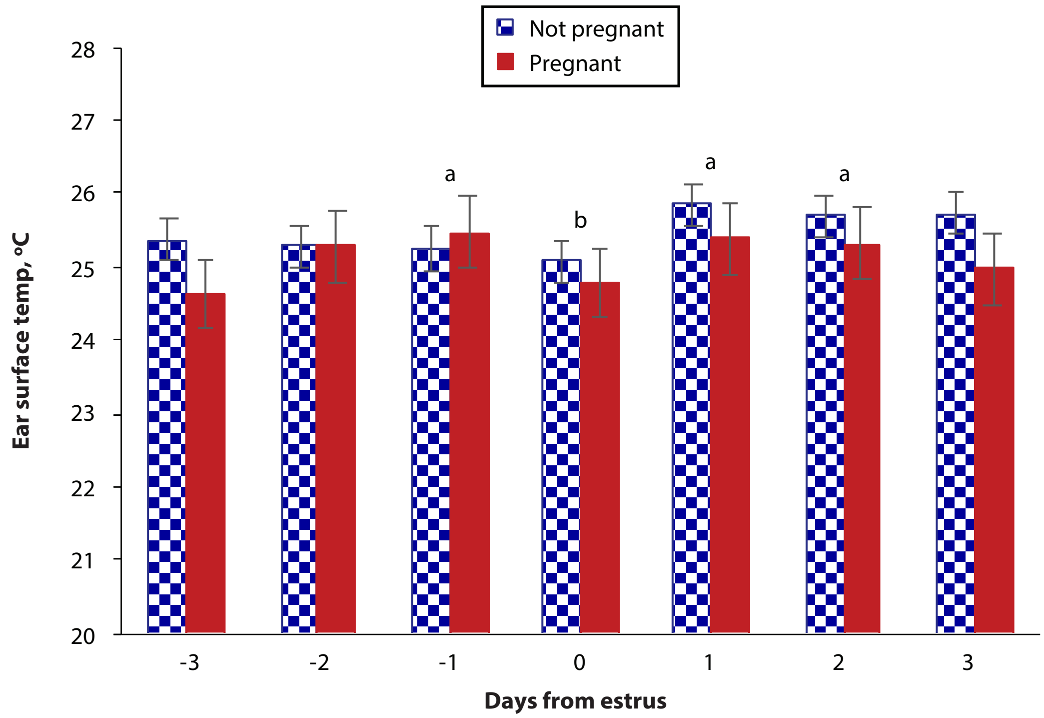

Figure 2. Daily ear-surface temperature (LSM ± SEM) during 3 days before estrus (day 0), estrus, and 3 days after estrus in cows that were diagnosed pregnant (n = 285) or not pregnant (n = 101). Pregnancy status was determined on day 32 ± 3 after estrus and insemination.
[a,b]Ear-surface temperature was less ($P < 0.01$) on day 0 than on days -1, 1, and 2.

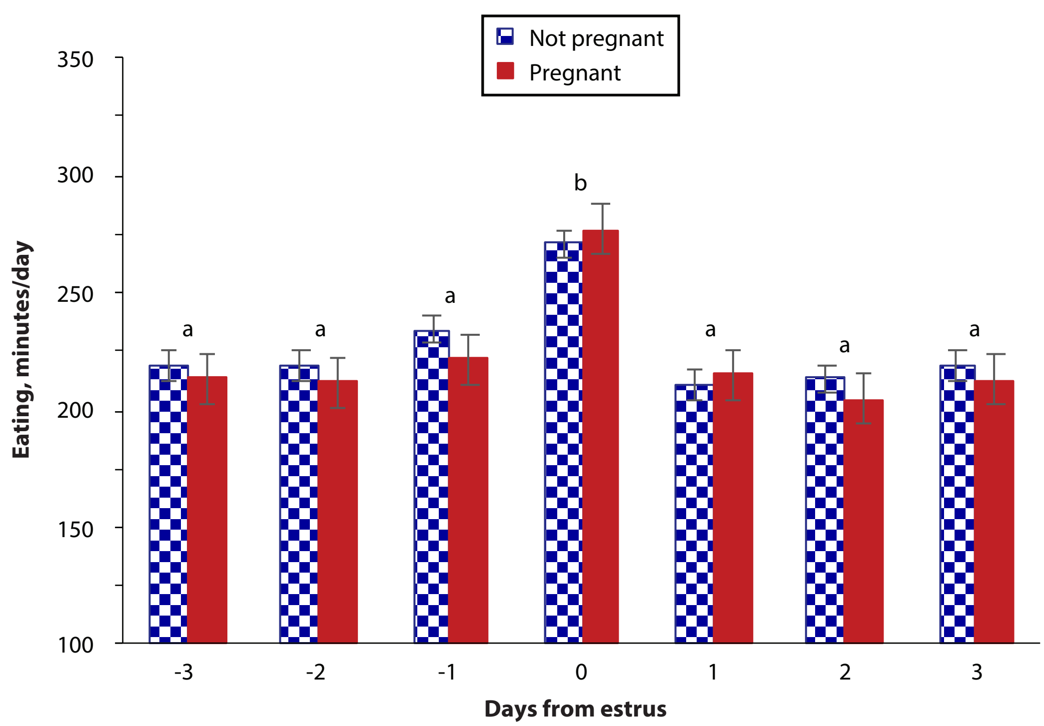

Figure 3. Daily eating time (LSM ± SEM) during 3 days before estrus (day 0), estrus, and after estrus in cows that were diagnosed pregnant (n = 285) or not pregnant (n = 101). Pregnancy status was determined on day 32 ± 3 after estrus and insemination.
[a,b]Eating time on day 0 was greater ($P < 0.01$) than either of the 3 days before or 3 days after estrus.

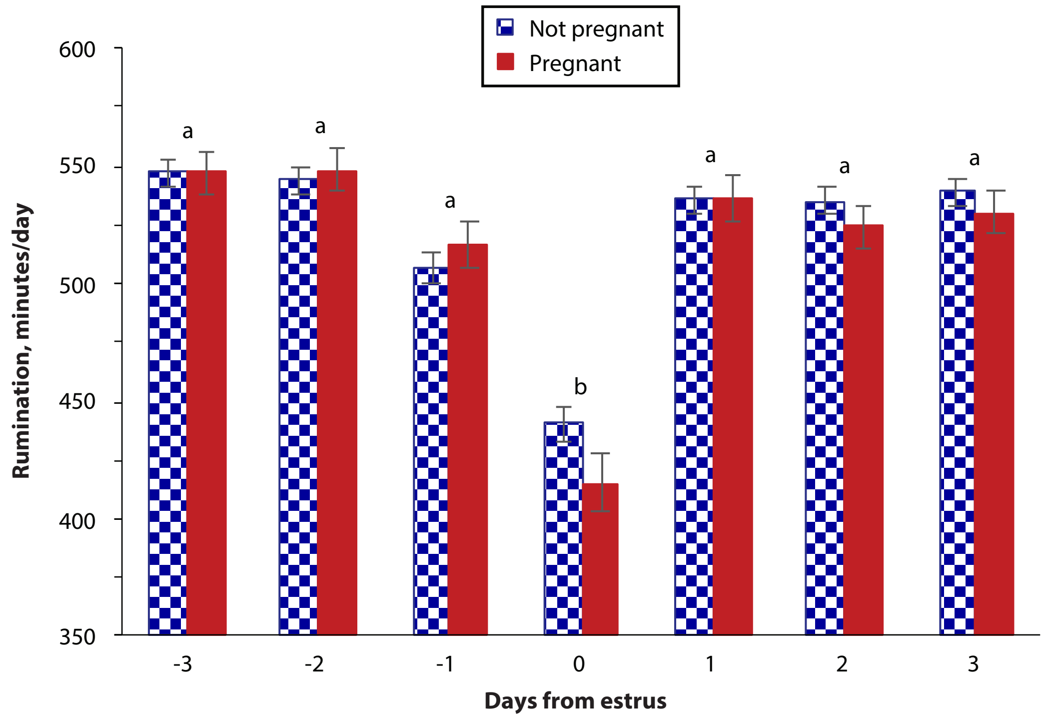

Figure 4. Daily rumination time (LSM ± SEM) during 3 days before estrus (day 0), estrus, and 3 days after estrus in cows that were diagnosed pregnant (n = 285) or not pregnant (n = 101). Pregnancy status was determined on day 32 ± 3 after estrus and insemination.
[a,b]Rumination time was less ($P < 0.01$) on day 0 than on either of the 3 days before or 3 days after estrus.

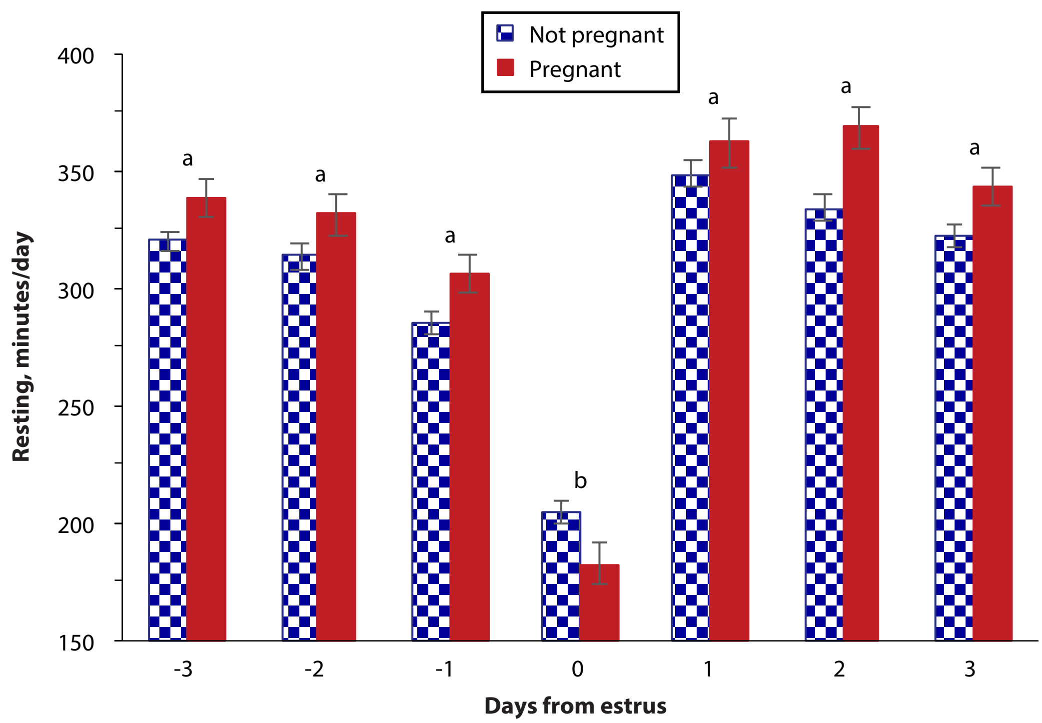

Figure 5. Daily resting (inactive) time (LSM ± SEM) during 3 days before estrus (day 0), estrus, and 3 days after estrus in cows that were diagnosed pregnant (n = 285) or not pregnant (n = 101). Pregnancy status was determined on day 32 ± 3 after estrus and insemination.
[a,b]Resting time was less ($P < 0.01$) on day 0 than on either of the 3 days before or 3 days after estrus.

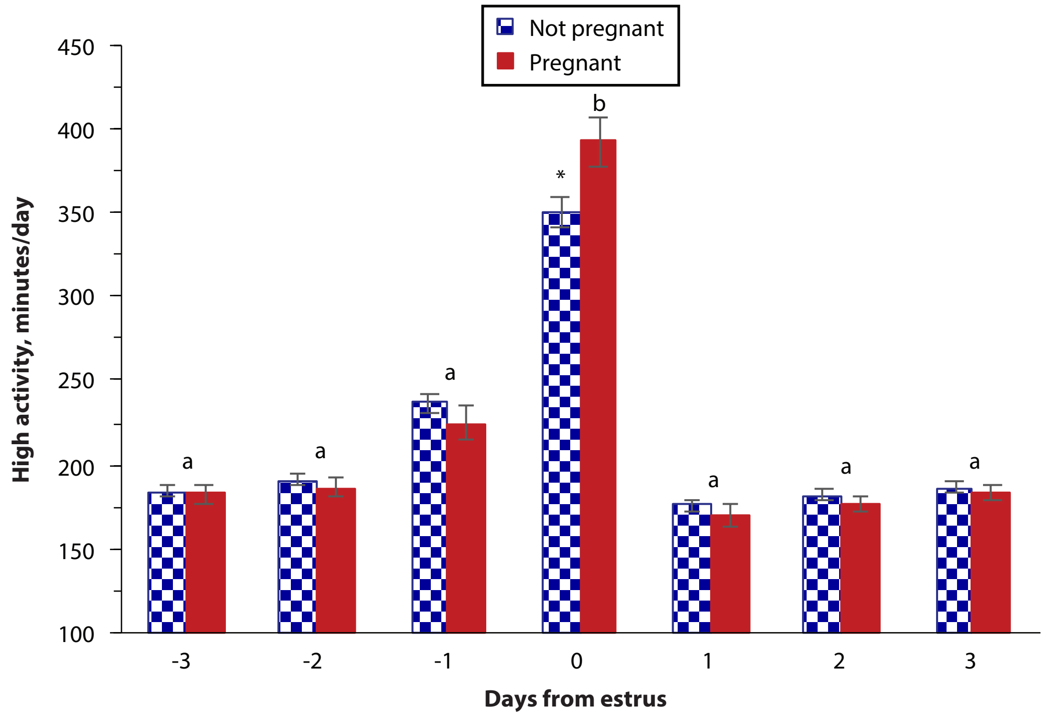

Figure 6. Daily high activity time (LSM ± SEM) during 3 days before estrus (day 0), estrus, and 3 days after estrus in cows that were diagnosed pregnant (n = 285) or not pregnant (n = 101). Pregnancy status was determined on day 32 ± 3 after estrus and insemination.
[a,b]High activity time was greater ($P < 0.01$) on day 0 than on either of the 3 days before or 3 days after estrus. *High activity was greater ($P < 0.05$) in cows diagnosed pregnant than in nonpregnant cows.