

Rumination and activity levels as predictors of calving for dairy cows

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The Australian dairy herd size has doubled over the last 20 years substantially increasing the time that farmers require for individual animal attention to monitor and intervene with events such as calving. Technology will help focus this limited labour resource on individual cows that require assistance. The objective of this experiment was to first determine the profiles of rumination duration and level of activity as determined by sensors between, and within, days around calving and second to use these data to predict the day of calving for pasture-based dairy cows. After 2 weeks from the expected calving date, 27 cows were fitted with SCR HR LD Tags, located in 40 × 90 m² paddock and offered ad libitum oaten hay and 2 kg grain-based concentrate/cow per day until calving. Hourly activity and rumination data for each cow, as determined by the SCR tags, were fitted with linear mixed models and all parameters were estimated using restricted maximum likelihood. Rumination duration decreased by 33% over the day prior and the day of calving, with the decline in rumination duration starting the day prepartum. Activity levels were maintained prepartum but increased in the days postpartum. The day of calving was recorded and used to determine the gold standard positive (the day before calving) and negative (all other) dates. A threshold rumination level of 0.9 (decline in rumination duration of 10%) gave the optimal combination of 70% sensitivity and 70% specificity. This experiment shows the potential to use rumination duration to predict the day of calving and the opportunity to use sensor data to monitor animal health.

Keywords: calving, prediction, sensor, rumination, pasture

Implications

New methods enabled by technology to monitor cows calving may help minimise the costs of dystocia and reduce the time that farmers spend on this task. Profiles of dairy cow rumination duration and activity level between, and within, days *peripartum* were determined. These data showed a distinct decline in the duration of rumination *prepartum* that was used as a method to predict the day of calving for dairy cows based outdoors on pasture.

Introduction

The average Australian dairy herd size has doubled from 120 to 240 cows/farm over the last 20 years (Dairy Australia, 2012), substantially increasing the time that farmers require for individual animal attention (Raussi, 2003). At the same

time, the prevalence of dystocia in dairy cows internationally is between 2% and 13% (Mee, 2008), with the upper limit of the range from the United States, the country where Australia currently sources the majority of its dairy genetics. This increasing herd size and incidence of dystocia together increases the risk of cow and calf mortality without a significant investment in farm labour. Alongside the labour and lifestyle issues for dairy farmers associated with this investment are the significant costs of dystocia on cow welfare (Barrier *et al.*, 2012) and a dairy enterprise's finances through decreased production and fertility, and increased cow and calf morbidity (Dematawewa and Berger, 1997). New methods enabled by technology to monitor cows calving may help minimise the costs of dystocia and reduce the time that farmers spend on this task.

There are various methods used to predict the timing of calving. Accurate record keeping enables calving to be predicted within a window of 10 days, given the range in the gestation period of a cow (280 ± 5 days) (Norton, 1956).

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Behavioural observations such as cows seeking isolation from the rest of the herd (Lidfors *et al.*, 1994), increases in restlessness (Owens *et al.*, 1985), transitions between standing and lying and tail raising (Miedema *et al.*, 2011) and a decline in rumination and feeding levels (Schirmann *et al.*, 2013) are also indicators of calving for cows offered a total mixed ration. As the timing and duration of rumination, feeding and activity differs substantially between housed (Schirmann *et al.*, 2012) and pasture-based grazing (Gregorini *et al.*, 2012) animals, the potential to use these behaviours to predict calving for pasture-based dairy cows is unknown.

Varying forms of technology are currently used to measure individual animal physiology, behaviour, and production to improve management strategies and dairy farm performance (Rutten *et al.*, 2013). Calving events have been successfully predicted using vaginal probes to monitor changes in temperature (Aoki *et al.*, 2005) and by video monitoring (Cangar *et al.*, 2008). However, these methods require a skill set such as the ability to suture the sensor in the correct position, additional labour to monitor video footage and are specific to the monitoring of calving. In contrast, rumination duration and activity level can be continuously monitored using collar-based systems. As rumination duration declines around calving for housed cows offered a total mixed ration (Schirmann *et al.*, 2013), there is potential to use rumination and activity sensors to predict the timing of calving for cows based outdoors on pasture.

The objective of this study was to first determine the profiles of rumination duration and level of activity between and within days for dairy cows *peripartum* and second to use these data to predict the day of calving.

Material and methods

The use of animals was approved by the Animal Ethics Committee of the University of Sydney (N00/5-2013/3/5998). The study was conducted at the University of Sydney's Corstorphine dairy research farm, Camden from 27 August to 8 October 2013. Two weeks before expected calving date, 27 cows were fitted with SCR heat and rumination long distance Tags (Hi Tag; SCR Engineers Ltd, Netanya, Israel). These collars consisted of an accelerometer to quantify activity and a microphone to monitor rumination, as validated by Schirmann *et al.* (2009). Both activity and rumination data were stored in 5-min intervals, which were downloaded to a farm computer and collated into mean hourly levels.

Cows were located in one 40 × 90 m² paddock and offered *ad libitum* oaten hay and taken to the milking facility once daily where they were offered 2 kg grain-based concentrate/cow per day until calving. Cows were then introduced to the main milking herd that were offered grazed pasture as their primary feed source. Farm staff monitored the calving paddock every hour through the day from a distance so as not to impact on behaviour. Calves were collected from cows the day post-calving and at the same time the cows were transferred to the main herd. The time of calving was recorded by farm staff.

Prediction of calving

'Prediction' of calving was classified as the ability to determine that a cow was going to calve on the following day. The change in rumination values across time were determined by:

- (i) Relating day of trial (t) with the previous day rumination duration ($t - 1$) (d_t/d_{t-1}) or;
- (ii) Relating day of trial with the average rumination duration for the previous 4 days ($(d_t/(d_{t-1}, d_{t-2}, d_{t-3}, d_{t-4})/4)$) as an exploratory analysis showed daily rumination and activity levels to be stable up to 4 days *prepartum* but the major change in rumination levels to occur in the 2 days *prepartum*.

Threshold levels of rumination change were created using 0.1 unit increments (where 0.1 is equivalent to 10%) with values ranging from 0.1 to 1.4 corresponding with the range in values obtained from the aforementioned methods. The gold standard for the prediction of calving day was day -1 (the day before calving) as calculated from the day of calving recorded by farm staff.

Change in rumination duration using the first (i) or second (ii) calculation determined above was classified as being a true positive value if the result from the calculation was less than the threshold level. The sensitivity and specificity of each threshold level was determined by relating the gold standard with rumination change. Sensitivity percentage was calculated as $100 \times \text{true positive}/(\text{true positive} + \text{false negative})$ and specificity percentage as $100 \times \text{true negative}/(\text{true negative} + \text{false positive})$.

Statistical analysis

Five minute activity data detailing the relative activity of each cow as an index was determined from an accelerometer and associated detailed algorithms and rumination duration determined by a built-in microphone were collated into hourly means for each cow to aid in the interpretation of the results. Hourly activity and rumination data for each cow were fitted with linear mixed models, and all parameters were estimated using restricted maximum likelihood procedure of Genstat for Windows version 14 (VSN International Ltd, Hemel Hempstead, Hertfordshire, UK).

To determine the effects of day relative to calving (t) (14 days before (days -14 to 0) to 14 days after calving (days 1 to 14)) on mean hourly activity level and rumination duration across each day, time was included in the model as a fixed effect and cow as a random effect. To examine the effects of time within a day on rumination or activity levels for the 5 days leading up to calving (days -5 to 0), a mixed linear model was fitted to hourly rumination and activity data for each cow. The standard error of the difference (s.e.d.) is reported describing the changes in rumination duration and activity level.

Results

Rumination duration (min/h) and activity level (units/h) *peripartum* are presented in Figure 1. There was an effect of rumination ($P < 0.01$; s.e.d. 1.5) and activity ($P < 0.01$,

s.e.d. 1.4) level with time. Rumination duration declined on average by 15% from day -2 to -1, and a further 18% from day -1 to the day of calving, representing an overall rumination duration decline of 33% as compared with rumination duration taken from days -3 to -14. There was a short-term rise in activity levels reaching ≈ 30 units/h by 2 days *postpartum*. Overall, *prepartum* (mean 24 units/h) and *postpartum* (mean 25 units/h) activity levels were similar. In contrast, rumination duration remained low in the days *postpartum*, reaching a stable level 5 days *postpartum*.

The duration of rumination and activity level within the 5 days pre-calving are shown in Figure 2a and b. Overall, with the exception of the day of calving (day 0), rumination and activity profiles were the inverse of each other with cows spending half of their time ruminating during the night (1800 to 0600 h) as compared with only a quarter of their time ruminating during the day (0600 to 1800 h). Rumination profiles of day -1 and the day of calving (day 0) differed to those on days -5 to -2 with a distinct decline in night time rumination duration on the day of calving.

The effect of changing threshold rumination duration on sensitivity and specificity of detecting the day before calving is shown in Figure 3a. The relative trade-off between true positive and false positive rates is given as the receiver operating characteristic (ROC) curve (Figure 3b). The greatest distance of the ROC curve from the line of no discrimination occurred at a sensitivity of ~ 0.7 .

Discussion

Rumination duration for cows in the current study decreased by 33% over the 2 days *prepartum*. In contrast, activity levels

were maintained *prepartum* but increased in the days *postpartum*. In line with our findings, Schirmann *et al.* (2013), when monitoring housed cows, showed rumination duration to decrease by 31% around the time of calving relative to 2 to 4 days *prepartum*, with half of this decrease occurring in the 24 h *postpartum* in line with the decreased dry matter intake and time spent feeding at this time (Miedema *et al.*, 2011). Together, these findings suggest that the decline of rumination levels in the lead up to calving is independent of system type, highlighting the opportunity to predict the timing of calving within a day and provide new insights into the behaviour of dairy cows *postpartum*.

Our findings are the first to show that the day of calving can be predicted for dairy cows based outdoors on pasture by the creation of threshold levels calculated by relating the day to day duration of rumination. Threshold values of 0.9 for both methods evaluated showed the greatest distance from the line of no discrimination towards perfect classification (the point 0.1), with sensitivity and specificity of $\sim 70\%$. In comparison with our method, Burfeind *et al.* (2011) using rectal and vaginal temperature loggers found a greater level of sensitivity (40% to 70%) but reduced specificity (80% to 85%) to predict calving within 24 h. Despite the greater specificity achieved by using temperature loggers, Burfeind *et al.* (2011) acknowledge that such loggers would not be practical on commercial dairy farms. Thus, there is further work required to significantly increase the sensitivity and specificity of practical methods to predict calving events. Analysing rumination and activity sensor data taken at a more frequent interval and/or by incorporating other sources of data into a calving prediction model will be avenues to explore in future research.

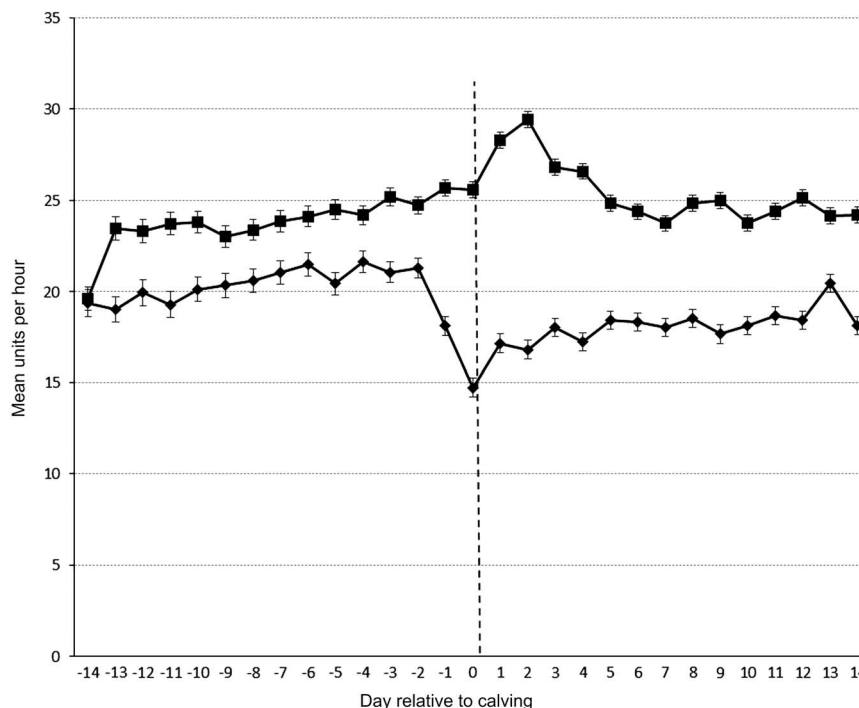


Figure 1 Mean (\pm s.e.) level of rumination (min/h) (diamond) and activity (units/h) (square) relative to the day of calving (day 0).

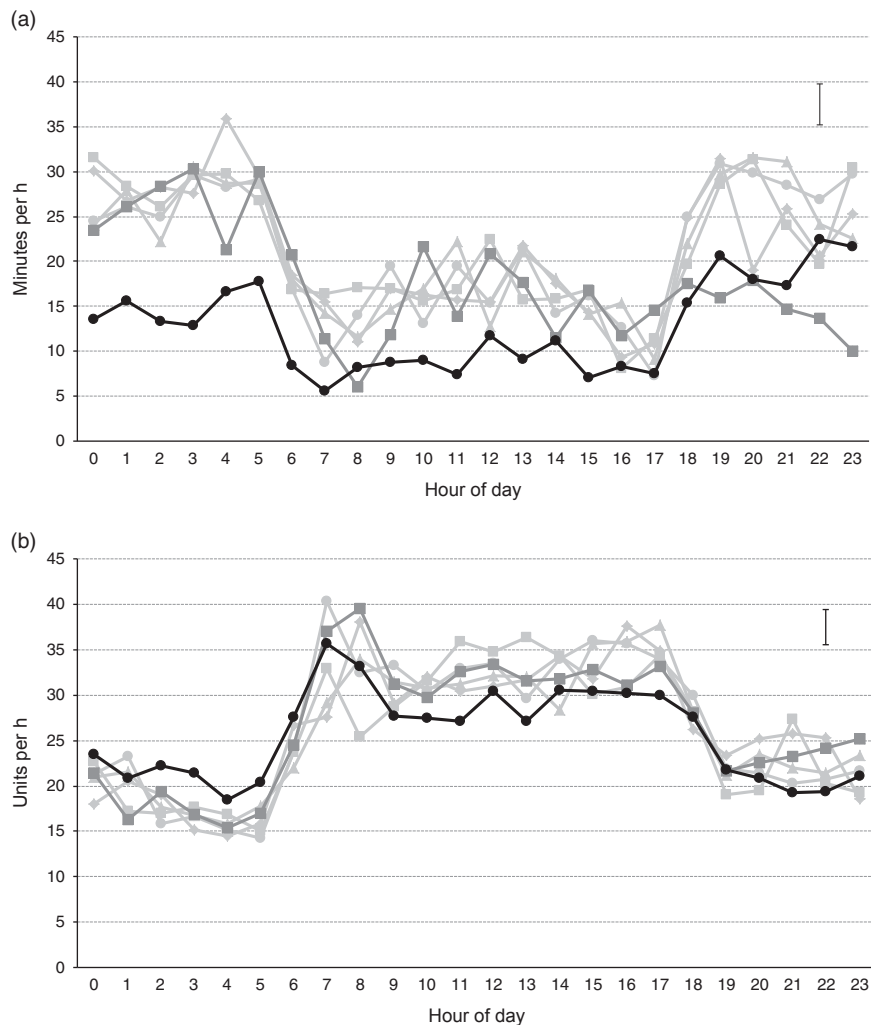


Figure 2 Mean level of rumination (a) and activity (b) (min/h) for day -5 to -2 (light grey), -1 (dark grey) and 0 (black). The error bar indicates the average s.e.d.

Rumination duration and activity level had a distinct inverse diurnal pattern in the current study. These findings are in line with previous research (Thomson *et al.*, 1985; Taweel *et al.*, 2004; Gregorini *et al.*, 2008), which reported the longest and most intensive rumination bouts to occur during the night, with rumen fill lowest at dawn. While these data provide insights into the behaviour of dairy cattle within a day *prepartum*, care must be taken in the interpretation of calving day profiles (Figure 2) of both rumination and activity as the timing of any calving event may have occurred at any hour. Despite this, these data highlight a clear opportunity to distinguish between calving cows and those that are not calving within a day, particularly using rumination duration in the early morning (midnight to 0500 h). Such detail may also allow the prediction of whether the dairy cow will require intervention to calve, which is the critical information that farmers require as a cow that is going to calve naturally requires less immediate attention. The opportunity to establish such a system is highlighted by Miedema (2009) and Barrier *et al.* (2012) who showed

unassisted or assisted cows without malpresentation spent significantly more time lying than those that were assisted with malpresentation. Thus, 'normal' profiles of behaviour leading to the final stages of parturition followed by an abnormally high duration of standing could predict the likelihood of dystocia and should be evaluated in further study.

As only 5 min are required for a dairy cow to establish a bond with its calf after birth (Hudson and Mallord, 1977), and calves were removed from cows soon after this time in the current study, the increase in activity of cows in the 2 days *postpartum* may have been associated with the breaking of this bond. To the best of the authors' knowledge, such findings are the first to be presented and give an insight into this behavioural aspect of dairy cows *postpartum*. Further work is required to define typical behaviours *postpartum* as abnormal profiles of activity and rumination could be useful early predictors of poor health given the prevalence of disease that occurs at this time (Dechow and Goodling, 2008).

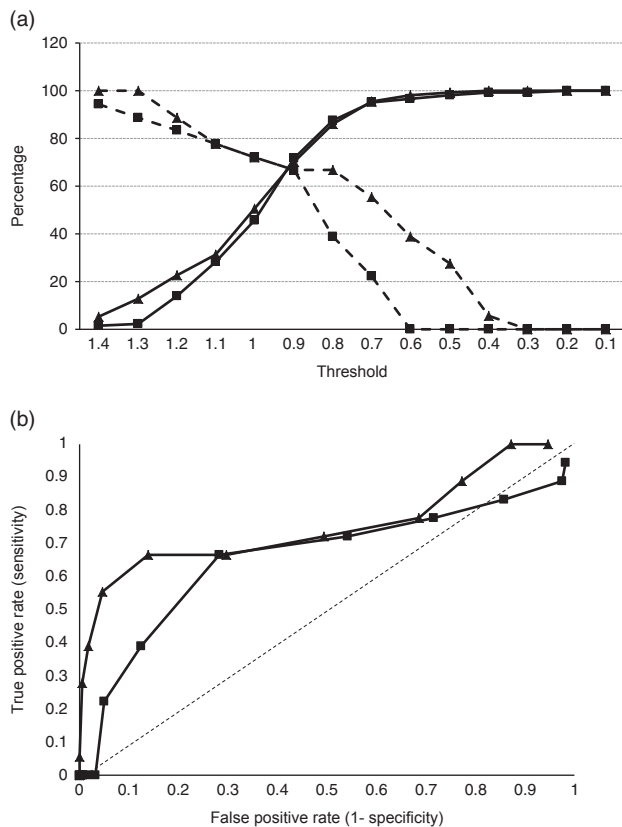


Figure 3 The effect of changing threshold rumination value calculated as today/yesterday mean rumination duration (min/h) (triangle) or today/previous 4 day mean rumination duration (min/h) (square) on (a) sensitivity (dashed line) and specificity (solid line) with a true positive being the day before calving and (b) receiver operating characteristic (ROC) curve where the dashed line is the line of no discrimination.

Conclusion

Profiles of rumination duration and activity level between and within days around calving were determined. These data showed a distinct decline in the duration of rumination *prepartum* that was used to successfully predict the day of calving for cows based outdoors on pasture. Further work is required to analyse rumination duration and levels of activity at reduced time intervals to predict the time of calving and whether assistance for calving is required.

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References

- Aoki M, Kimura K and Suzuki O 2005. Predicting time of parturition from changing vaginal temperature measured by data-logging apparatus in beef cows with twin foetuses. *Animal Reproduction Science* 86, 1–12.
- Barrier AC, Ruelle E, Haskell MJ and Dwyer CM 2012. Effect of a difficult calving on the vigour of the calf, the onset of maternal behaviour, and some behavioural indicators of pain in the dam. *Preventative Veterinary Medicine* 103, 248–256.
- Burfeind O, Suthar VS, Voigtsberger R, Bonk S and Heuwieser W 2011. Validity of prepartum changes in vaginal and rectal temperature to predict calving in dairy cows. *Journal of Dairy Science* 94, 5053–5061.
- Cangar O, Leroy T, Guarino M, Vranken E, Fallon R, Lenehan J, Meed J and Berckmans D 2008. Automatic real-time monitoring of locomotion and posture behaviour of pregnant cows prior to calving using online image analysis. *Computers and Electronics in Agriculture* 64, 53–60.
- Dairy Australia 2012. *Australian Dairy Industry in focus 2012*. Victoria, Australia.
- Dechow CD and Goodling RC 2008. Mortality, culling by sixty days in milk, and production profiles in high- and low-survival Pennsylvania herds. *Journal of Dairy Science* 91, 4630–4639.
- Dematawewa CMB and Berger PJ 1997. Effect of dystocia on yield, fertility and cow losses and an economic evaluation of dystocia scores for Holsteins. *Journal of Dairy Science* 80, 754–761.
- Gregorini P, Gunter SA, Beck PA, Soder KJ and Tamminga S 2008. Review: the interaction of diurnal grazing pattern, ruminal metabolism, nutrient supply and management in cattle. *The Professional Animal Scientist* 24, 308–318.
- Gregorini P, DelaRue B, McLeod K, Clark CEF, Glassey CB and Jago J 2012. Rumination behavior of grazing dairy cows in response to restricted time at pasture. *Livestock Science* 146, 95–98.
- Hudson SJ and Mullord MM 1977. Investigations of maternal bonding in dairy cattle. *Applied Animal Ethology* 3, 271–276.
- Lidfors LM, Moran D, Jung J, Jensen P and Castren H 1994. Behaviour at calving and choice of calving place in cattle kept in different environments. *Applied Animal Behaviour Science* 42, 11–28.
- Mee JF 2008. Prevalence and risk factors for dystocia in dairy cattle: a review. *Veterinary Journal* 176, 93–101.
- Miedema H 2009. Investigating the use of behavioural, accelerometer, heart rate measurements to predict calving in dairy cows. PhD Thesis, University of Edinburgh.
- Miedema HM, Cockram MS, Dwyer CM and Macrae AI 2011. Behavioural predictors of the start of normal and dystocic calving in dairy cows and heifers. *Applied Animal Behaviour Science* 132, 14–19.
- Norton HW 1956. Gestation period for Holstein-Friesian cows. *Journal of Dairy Science* 39, 1619–1621.
- Owens JL, Edey TN, Bindon BM and Piper LR 1985. Parturient behaviour and calf survival in a herd selected for twinning. *Applied Animal Behaviour Science* 13, 321–333.
- Raussi S 2003. Human–cattle interactions in group housing. *Applied Animal Behaviour Science* 80, 245–262.
- Rutten CJ, Velthuis AGJ, Steeneveld W and Hogeveen H 2013. Invited review: sensors to support health management on dairy farms. *Journal of Dairy Science* 96, 1928–1952.
- Schirmann K, von Keyserlingk MA, Weary DM, Veira DM and Heuwieser W 2009. Technical note: validation of a system for monitoring rumination in dairy cows. *Journal of Dairy Science* 92, 6052–6055.
- Schirmann K, Chapinal N, Weary DM, Heuwieser W and von Keyserlingk MA 2012. Rumination and its relationship to feeding and lying behaviour in Holstein dairy cows. *Journal of Dairy Science* 95, 3212–3217.
- Schirmann K, Chapinal N, Weary DM, Vickers L and von Keyserlingk MA 2013. Short communication: rumination and feeding behaviour before and after calving in dairy cows. *Journal of Dairy Science* 96, 7088–7092.
- Taweel HZ, Tas BM, Dijkstra J and Tamminga S 2004. Intake regulation and grazing behavior of dairy cows under continuous stocking. *Journal of Dairy Science* 87, 3417–3427.
- Thomson BC, Cruickshank GJ, Poppi DP and Sykes AR 1985. Diurnal patterns of rumen fill in grazing sheep. *Proceedings of the New Zealand Society of Animal Production* 45, 117–120.