Remote sensing of heart rate and rumen temperature in feedlot beef cattle: associations with feeding and activity patterns.

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Abstract

Heart rate (HR; beats/min) rumen temperature (RTMP; ºC), activity level (ACT; %) and feeding patterns (feeding event duration; sec/30 min, feed intake; kg/30 min, visits to the feeder; visits/30 min) have been suggested as feed efficiency (residual feed intake; RFI; kg/d), distress and health status indicators in cattle holding potential for development into practical on-farm decision making tools. Our study assessed the associations between these parameters when feedlot cattle (n=22) were eating or not eating (FI dataset), at differing activity levels (ACT dataset) and between feed efficient and feed inefficient cattle (RFI dataset). Heart rate was not different between FI, ACT and RFI groups. RTMP was lower in high ACT then low ACT observations (39.64±0.15 vs 40.08±0.15; P=0.001) and was associated with ACT in positive RFI cattle (r=-0.55; P <0.001). Activity levels in the ACT dataset were lower when cattle were located in the yard then when located in the pen or abattoir. Associations between RTMP and ACT across ACT and RFI datasets promote these as potential indicators of feed efficiency and health status in cattle. Changes in ACT across locations suggest it to be a potential indicator of distress. Future studies assessing RTMP and ACT abilities to determine performance are warranted.

Keywords: accelerometer; cardiac rhythm; feed efficiency; radio-telemetry; rumen bolus

Introduction

Objective and prompt determination of animal productivity, efficiency and health status is essential for a profitable and sustainable beef cattle industry. Studies have determined heart rate (Hafla et al. 2013; Montanholi et al. 2014) activity patterns (Brown et al. 2013) and feeding patterns (Montanholi et al. 2010) to be indicators of feed efficiency (residual feed intake; RFI; kg/d) and energy expenditure in beef cattle. In addition, feeding patterns (González et al. 2008) and rumen temperature (Rose-Dye et al. 2011) are associated with physiological and pathological status in cattle. For example, Rose-Dye et al. (2011) observed an increase in rumen temperature in steers challenged with pathogens. There is an opportunity for technologies that continuously monitor biological parameters to facilitate decision making on commercial farms.

Recent developments in radio-telemetry have allowed for the non-invasive assessment of biological parameters across various husbandry practices. Signer et al. (2010) developed a system that continuously assesses heart rate, rumen temperature and activity level in free-ranging ruminants. Differences in heart rate, rumen temperature or activity level between husbandry practices could indicate the level of distress each practice causes. The recording of feeding patterns in addition to long-term monitoring of heart rate, rumen temperature and activity allow the associations between each of these parameters to be assessed. Associations between these parameters could result in the identification of practical on-farm decision making tools.

The objectives of this study were to assess associations between heart rate, rumen temperature, activity level and feeding patterns in feedlot cattle when (1) cattle are eating or not eating, (2) cattle are exhibiting different activity levels and (3) between feed efficient and feed inefficient cattle.

Materials and methods

Cattle herds and husbandry

Beef cattle (14 to 18 months of age) selected from three herds; summer steers (SS; n=79), summer bulls (SB; n=16) and autumn steers (AS; n=16) were used in this study. Within each herd, experimental animals were selected based on divergent values for residual feed intake (RFI; kg/day). This resulted in three sub-populations monitored with a radio-telemetry system; SS=8, SB=8, AS=6 with equal numbers of high RFI (HRFI) and low RFI (LRFI) animals in each. Animals were housed and studied in a group pen facility (Elora Beef Research Centre, Elora, Canada) bedded with wood shavings. Animals were fed *ad libitum* a predominantly high-moisture corn and corn silage diet (Montanholi et al. 2010). The study was approved by the Animal Care Committee of the University of Guelph.

Telemetry system and feeding pattern assessment

A radio-telemetry system (Mortality Implant Transmitter; (MIT) and collar unit (Vectronic Aerospace GmbH, Berlin, Germany) was used to assess heart rate (HR; bpm), rumen temperature (RTMP; ºC) and activity (ACT; %). The MIT (bolus) and collar unit are described by (Signer et al. 2010). Briefly, the MIT using an acceleration sensor, recorded the HR of the animal by detecting mechanical shockwaves caused by the heart. On three minute intervals the HR detected and RTMP recorded were sent via ultra-high frequency to the collar unit. Activity was determined from the collar unit by detecting and recording the duration of omnidirectional movements over each three minute recording interval. Activity level was quantified as the percentage of time active during the interval. Data was retrieved and analyzed from the collar unit using RumiLog© software (Research Institute of Wildlife Ecology, Vienna, Austria). This system has been validated in sheep during periods of rest or minimal activity (Signer et al. 2010).

The MIT was inserted using a tube placed on top of the tongue that delivered the MIT into the reticulum. The collar unit was attached around the animal's neck. Sub-populations were monitored separately; (1) SS, (2) SB and (3) AS and animals were monitored for either 3 to 7 days (n=11) or for 8 to 16 hours (n=11). Heart rate, RTMP and ACT values were classified into pen (PEN), yard (YRD), transport (TRN) and abattoir (ABT) depending on where the animal was located throughout the monitoring period.

Feeding patterns were assessed using an automated feed recording system (Insentec, B.V. Marknesse, The Netherlands) that was similar to the feeding stations described by Tolkamp & Kyriazakis (1997). A further description of system mechanics and its determination of feeding patterns is provided by Montanholi et al. (2010). Briefly, the systems recording of individual feed events were used to calculate the duration of each feeding event (FDUR; seconds/30min), the intake of each feeding event (FI; kg/30min) and the number of visits to the feeder (VST; VST/30min).

Residual feed intake calculation

Ultrasound and live weight (LW) assessments occurred on 28 day intervals over 112 days prior to the start of the monitoring period. Ultrasound traits; back fat thickness (mm), rib eye area (cm^2), rump fat thickness (mm) and marbling score (score; 0-devoid to 11-abundant) were determined. Live weights were recorded using a calibrated weigh scale (Silencer Hydraulic Squeeze Chute, Moly Manufacturing Inc., Lorraine, USA). Residual feed intake was calculated using methods adapted from Montanholi et al. (2010). Average feed intake (AFI) was calculated using feed intake data that had a 98% or greater probability of belonging to the normal distribution. Average daily gain (ADG) was computed as the coefficient of linear regression of LW on time of measurement. Predicted feed intake was calculated by including ADG, LW and ultrasound traits into a combined linear regression model.

Statistical analysis

Data were analyzed using SAS version 9.3. Due to differences in raw recording frequencies, data collected were averaged (HR, RTMP and ACT) or summed (FDUR, FI and VST) over 30-minute intervals. Observations containing no HR value or obvious outliers for all traits were removed using PROC UNIVARIATE. Observations were then grouped using three different criteria. One, based on RFI into positive (PRFI) and negative (NRFI) RFI groups (RFI dataset; n=380). Two, observations that had a positive (PFI) or zero (ZFI) value for feed intake (FI dataset; n=140). Three, removing all observations that did not include an ACT value (ACT dataset; n=333), then grouping based on ACT into; (1) low (LACT; 2-29%), (2) medium (MACT; 30-43%) and (3) high (HACT; 44-75%). Descriptive statistics were then determined for each data set using PROC UNIVARIATE. Using PROC MIXED the following statistical model was developed:

$$Y_{ijk} = \mu + DAY_i + HERD_j + \varepsilon_{ijk}$$

where Y_{ijk} is the trait observation on the i^{th} day, taken from the j^{th} herd and associated with the k^{th} error; μ is the overall mean for the trait; DAY_i is the fixed effect of the i^{th} day; $HERD_j$ is the fixed effect of the j^{th} herd; and ε_{ijk} is the residual random effect associated with the traits measurement on the i^{th} day taken from the j^{th} population associated with the k^{th} error. The LSMEANS and REPEATED (time within day) statements within PROC MIXED were used to compare trait means between RFI, FI and ACT groups and over the circadian period. Phenotypic correlations were assessed using PROC CORR. Results were statistically significant when $P \leq 0.05$ and a trend towards significance when $0.10 \geq P > 0.05$.

Results

Figure 1 profiles the circadian patterns of HR, RTMP and ACT traits while animals were housed in the penned facility. In the HACT observations, HR was correlated with ACT (r=-0.20; P=0.04). There was no difference in HR across RFI, FI or ACT groups or between HACT and LACT when comparing group means across the circadian profile (Fig. 2).

Rumen temperature was lower in HACT then LACT (39.64±0.15°C vs. 40.08±0.15°C; P<0.001) (Fig. 2). A correlation between ACT and RTMP was observed in PRFI cattle (r=-0.55; P<0.001) and suggested for NRFI cattle (r=-0.11; P=0.09). A correlation was found between RTMP and HR in MACT (r=0.20; P=0.04) and HACT (r=0.22; P=0.02) observations. A correlation was also observed between RTMP and HR in NRFI cattle (r=0.14; P=0.02). Feeding patterns (FDUR, FI and VST) were not different across RFI or ACT groups. A correlation was observed between VST and RTMP in PRFI cattle (r=-0.68; P=0.01) along with a trend towards significance in MACT (r=-0.43, P=0.10).

Heart rate and RTMP were not different across the four events animals endured (Fig. 3). Activity levels in the ACT data set were lower when located in YRD then when located in PEN or ABT (23.79±4.69% vs. 34.16±3.35%, 23.79±4.69% vs. 45.36±8.12%; P=0.02, P=0.04) (Fig. 3).

Discussion

Trait means for HR (Table 1) agreed with previous studies in beef bulls (68.9 to 77.6 beats/min) (Montanholi et al. 2014) and were in line with values for beef cows (Hafla et al. 2013). Rumen temperature results were in concurrence with results observed elsewhere (Rose-Dye

Table 1 Descriptive statistics of heart rate (HR; beats/min), rumen temperature (RTMP; °C), activity levels (ACT; %) and feeding patterns (feeding event duration; FDUR; sec/30min, feed intake; FI; kg/30min, visits to the feeder; VST; visits/30min) across observations and animals.

Trait	Mean	Minimum	Maximum	Standard Deviation
Across observations				
Heart rate (HR; beats/min)	72.5	40.7	119.3	16.5
Rumen temperature (RTMP; °C)	39.69	34.80	41.94	0.88
Activity level (ACT; %)	36.8	2.3	74.6	15.3
Feeding event duration (FDUR; sec/30min)	173	0	696	120
Feed intake (FI; kg/30min)	1.16	0.00	4.50	0.91
Visits to feeder (VST; visits/30min)	2.17	0.00	8.00	1.57
Across animals				
Heart rate (HR; beats/min)	71.5	49.4	95.8	12.5
Rumen temperature (RTMP; °C)	39.83	39.07	40.56	0.42
Activity level (ACT; %)	33.4	17.6	48.0	8.2
Feeding event duration (FDUR; sec/30min)	176	72	288	55
Feed intake (FI; kg/30min)	1.00	0.50	1.48	0.31
Visits to feeder (VST; visits/30min)	2.16	1.00	4.00	0.81

et al. 2011). Activity levels were comparable with observations in red deer (Turbill et al. 2011) and circadian patterns agreed with those observed in sheep (Signer et al. 2010). Daily total FDUR agreed with results in feedlot beef cattle found elsewhere (Hafla et al. 2013; Montanholi et al. 2010).

The lack of difference in HR between RFI groups disagrees with the results of other experiments in beef cattle where low RFI beef cattle had a higher HR (Hafla et al. 2013; Montanholi et al. 2014). During periods of rumination and high-activity, the acceleration sensor and HR determining algorithm can be biased (Signer et al. 2010; Turbill et al. 2011). Heart rate was recorded during both rumination and periods of high-activity in this experiment. Hafla et al. (2013) and Montanholi et al. (2014) recorded HR using an external electrode system that only measures electrical impulses. The negative association between HR and ACT during periods of HACT agrees with the results of Turbill et al. (2011), suggesting that the decreased HR during periods of HACT could be an artifact caused by high-activity. The presence of these artifacts could have caused a low HR value which could explain the absence of a relationship between HR and RFI. In addition, the small number of observations used in this study compared to others could have contributed to this result.

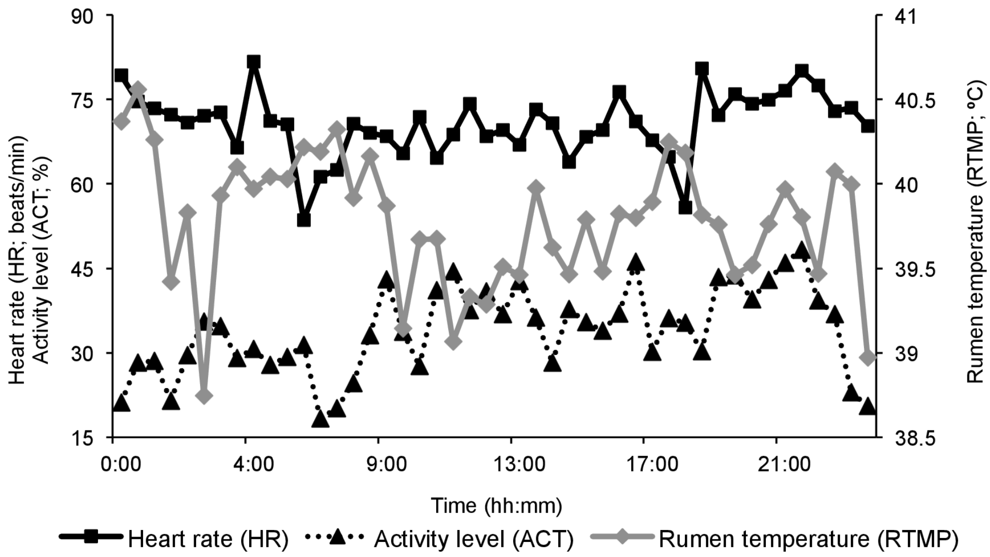

Figure 1 Circadian profile for heart rate (HR; beats/min), activity level (ACT; %) and rumen temperature (RTMP; ºC) obtained using a radio-telemetry system in feedlot cattle.

Lower RTMP during periods of HACT seen across ACT groups and over the circadian period can be explained by the relationship between rumen activity and metabolic rate. Low-activity animals will potentially spend more time lying, a parameter associated with rumination time (Schirmann et al. 2012). Increased rumination during periods of low-activity or lying results in repeated mastication and swallowing of the feed bolus. These processes promote both microbial activity and an increase in metabolic rate resulting in increased heat production and consequently RTMP fluctuations (Van Soest 1994). The negative correlation between VST and RTMP during MACT supports this explanation, as animals that spend less time at the feeder could spend more time ruminating

(Schirmann et al. 2012). The positive relationship between metabolic rate and RTMP (Van Soest 1994) and the positive association between HR and metabolic rate (Benedict 1924) explains the positive association between HR and RTMP. Figure 2 shows that the LACT circadian profiles of HR track those of RTMP during the early period of the day. This association is also seen as the day progresses, except that changes in HR occur after changes in RTMP (Fig. 2). However, this association was not seen when looking across all observations before grouping into RFI, FI and ACT datasets occurred (Fig. 1), suggesting the importance of activity in the RTMP and HR relationship.

Activity and RTMP could also be related to feed efficiency as suggested by the changing strength of the relationship between RTMP and ACT between NRFI and PRFI cattle. The weak negative correlation between these two parameters in NRFI cattle is contrasting to the association observed in PRFI cattle and indicates that during low activity NRFI cattle have a lower radiant heat production resulting in a weaker association with increased RTMP when compared with PRFI. This suggests that through monitoring the relative changes of RTMP and ACT the feed efficiency of an animal could be indicated.

The similarity of HR across husbandry practices disagrees with previous observations in beef bulls (Montanholi et al. 2014), the artifacts caused by high-activity could have contributed to this result. Rumen temperature is dependent on changes in metabolic rate, feed and water intake and eructation (Van Soest 1994). As such changes in RTMP occur at a slower rate and are more indicative of long-term stressors (Rose-Dye et al. 2011) explaining the absence of a difference between husbandry practices. The change in ACT across husbandry practises suggests that it could be an accurate indicator of distress. Activity is also a characteristic of temperament (chute exit speed) which impacts productive, reproductive and health performance (Cooke et al. 2014) suggesting that activity could have broad applications as a management tool.

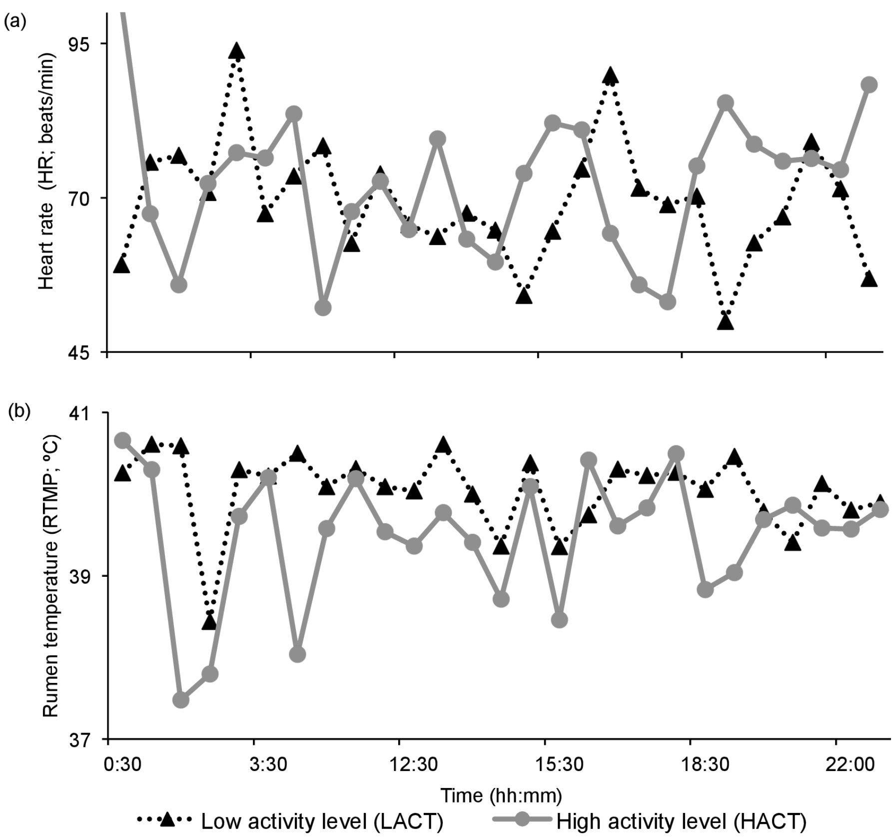

Figure 2 Circadian profile for heart rate (HR; beats/min) and rumen temperature (RTMP; ºC) between LACT (2-29% of time active) and HACT (43-75% of time active) groups of cattle. (a) HR for HACT and LACT groups. (b) RTMP for HACT and LACT groups.

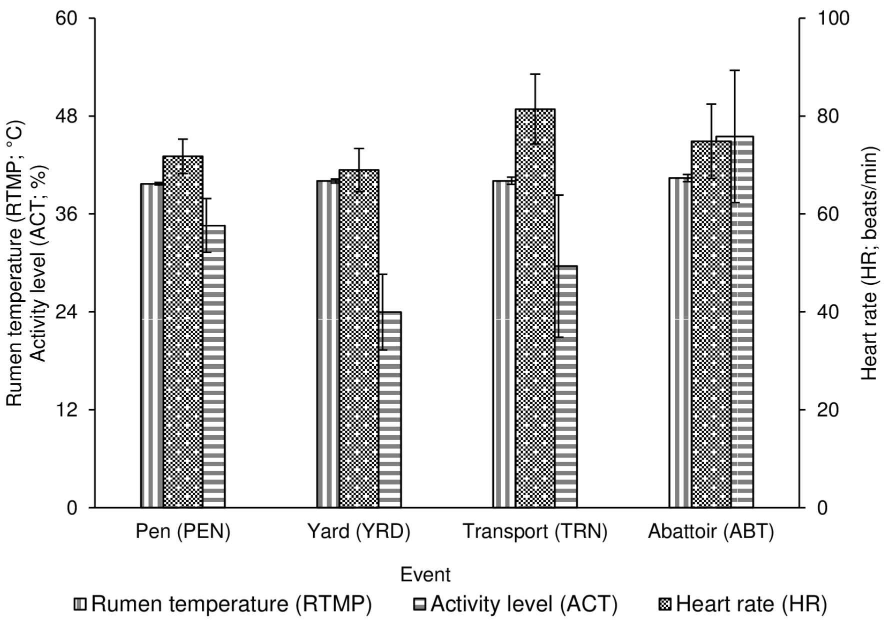

Figure 3 Means of rumen temperature (RTMP; °C), heart rate (HR; beats/min) and activity level (ACT; %) across the four locations encountered (pen; PEN, yard; YRD, transport; TRN, abattoir; ABT) in feedlot cattle.

Conclusion

Heart rate determined using a radio-telemetry system was not different across residual feed intake, feed intake or activity level groups. Extending the monitoring period and focusing on periods of rest may reduce the likelihood of bias and increase the volume of usable HR data. The multiple relationships between rumen temperature and activity in both the activity and residual feed intake groupings reveals the potential for rumen temperature and activity to be used as indicators of feed efficiency and health status on commercial farms. The changes in activity level across routine husbandry practices suggests that activity level is an indicator of distress. Future studies directly assessing the ability of relative changes in RTMP and ACT to determine feed efficiency, distress and health status are warranted.

Acknowledgements

The completion of this study was funded by a Graduate Research Training Initiative Scholarship through Growing Forward 2 Program, Beef Cattle Research Council, Agriculture and Agri-Food Canada, Beef Farmers of Ontario and Ontario Ministry of Agriculture Food and Rural Affairs. Thanks are given to Perica Jurcevic for compiling the heart rate, rumen temperature and activity data. The assistance provided by the staff at EBRC and students is also appreciated.

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