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Impact of digital dermatitis on feedlot cattle behaviour

Anice D. Thomas, Karin Orsel, Julián A. Cortés, Edmond A. Pajor [*]

Department of Production Animal Health, University of Calgary, Faculty of Veterinary Medicine, 3280 Hospital Drive NW, Calgary, AB T2N 4Z6, Canada

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ABSTRACT

Digital dermatitis (DD) is an infectious disease affecting the bovine digital skin which can cause lameness and significantly affect animal welfare and economics. Digital dermatitis has emerged in feedlots and early identification of DD lesions is difficult using traditional visual methods. The objective of this study was to determine if changes in behaviour: rumination, feeding, inactivity and activity could be associated with DD in beef heifers and if these behaviours differed among DD M-stages ('M' for Mortellaro; 6-point classification describing the life cycle of DD). On arrival at the feedlot 120 heifers were fitted with accelerometers (CowManager system) attached to their Radio-frequency identification (RFID) tags to measure time spent ruminating, feeding, activity (walking and movement) and inactivity (lying and standing) throughout the feeding period. The study was conducted from November 2018 to November 2019 with heifer placements in fall 2018 and winter 2019. Biweekly pen walks were conducted to assess hind feet for presence or absence of DD using the M-stage scoring system and for altered gait using a lameness score. Detailed foot examination was conducted for heifers selected during pen walks, at routine re-handling events and prior to transport to the abattoir. In total 51 of 114 (44.74%) heifers were afflicted with DD. Among DD affected heifers 26 were classified as having active lesions and 25 as having chronic lesions. Behaviour pattern 5–2 days before detailed foot examination was analysed. Mean time spent ruminating ranged from 16% to 20%. Rumination time was significantly greater in heifers without DD lesions ($P = 0.008$) compared to DD affected heifers that ruminated 3% less per day. The effect of Day on mean daily rumination time depended on whether heifers had active DD lesions, chronic DD lesions or no lesion present ($P = 0.034$). Heifers with active DD lesions ruminated 5% less ($P = 0.002$) than heifers with no lesions. Mean time spent inactive ranged from 46% to 49% and was significantly greater in heifers with DD lesions ($P = 0.035$). The effect of Day on mean inactivity time depended on whether heifers presented with an active DD lesion, a chronic DD lesion or no lesion ($P = 0.047$). In conclusion, rumination is depressed, and inactivity increased in heifers with DD, 5–2 days before diagnosis. Taken together, our results describe the impact of DD on beef heifer behaviour and the potential utility of behaviour for early detection of DD.

1. Introduction

Digital dermatitis (DD) is an infectious skin disease affecting the heel bulbs of cattle (Cheli and Mortellaro, 1974) and is characterised as a circumscribed erosive or papillomatous lesion which can cause lameness (Read and Walker, 1998) and significantly impacts animal welfare, production, and economics (Orsel et al., 2018). Over time, there has been an increasing awareness of DD in feedlot cattle with reported prevalence ranging from 4% to 61% in North America (Brown et al., 2000; Kulow et al., 2017) and 11% in Australia (Hesseling et al., 2019). It is still unclear how and when animals develop DD in the feedlot.

Feedlot management practices include daily pen health checks for signs of illness, injury, or distress. Currently, DD animals are identified after clinical signs appear (lesion and or lameness) at which point the disease reservoirs have already been formed and success from treatment with topical antibiotic preparations is variable (Berry et al., 2010; Cutler et al., 2013; Krull et al., 2016). Early signs of DD such as initial lesion development or mild lameness are hard to detect during pen health checks because cattle are stoic and mask behavioural responses to disease (Weary et al., 2006). Additionally, some animals with DD lesions do not present with altered gait (van Huyssteen et al., 2020). Wet and muddy pen conditions also increase the difficulty of visual lesion identification.

An alternative to visual observations of animal behaviour is the use of remote sensing technologies such as accelerometers that have accurately quantified behaviour and monitored the disease state of cattle

* Corresponding author.
E-mail address: eapajor@ucalgary.ca (E.A. Pajor).

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(Theurer et al., 2013; Richeson et al., 2018). Behaviours, such as activity, rumination and feeding, have been used to support health management decisions on dairy farms since the 1980s (Rutten et al., 2013) and are becoming more popular in the beef industry. For example, Wolfger et al. (2015b) and Naaktgeboren et al. (2017) validated the use of the CowManager system (Agis, Harmelen, The Netherlands) to monitor rumination, feeding, activity and inactivity behaviour in beef cattle. These behaviours quantified have also been used to predict bovine respiratory disease (BRD) and lameness prior to visible clinical signs in feedlot cattle (Wolfger et al., 2015a; Marchesini et al., 2018).

The use of remote technologies that can record and analyse behavioural changes could result in early detection, more effective treatment, and improved animal welfare. This study had two objectives; the first was to determine if changes in time spent ruminating, feeding, activity (walking and movement) and inactivity (lying and standing) could be associated with DD in beef heifers, and secondly to determine if these behaviours differed among DD M-stages ('M' for Mortellaro; no lesion, acute lesion, and chronic lesion).

2. Material and methods

This study was approved by the University of Calgary Veterinary Services Animal Care Committee (AC17–0224) in accordance with the ethical principles of the Canadian Council on Animal Care. Written informed consent was obtained from the owner at the participating feedlot for the use of their animals in the study.

2.1. Feedlot and animal selection

The study was conducted from November 2018 to November 2019 at one feedlot located in southern Alberta, Canada. This feedlot was a good representation of the feedlot industry in Western Canada having a total capacity of 10,000 animals housed in outdoor dirt pens protected with wind breakers. The feedlot selection criteria included: a known history of DD (within-pen DD outbreak within the last 3 years), a working squeeze chute, cattle from auction marts, the CowManager system currently installed and a willingness to participate.

On arrival at the feedlot, 120 of 1733 heifers (calves and yearlings) were randomly selected using a stratified systematic sampling method and processed in accordance with feedlot management protocols which included assigning cattle a feedlot ID (colour coded and numbered plastic ear tag), vaccination, parasiticide, and growth-promoting agents. Arrival date varied by pen from November 2018 to March 2019. Calves were 8–10 months of age and had an initial mean body weight of 252 kg (SD ± 45 kg, n = 84). Yearlings were 11–13 months of age and had an initial mean body weight of 390 kg (SD ± 42 kg, n = 36). All heifers in the study, were housed in six outdoor dirt pens bedded with barley and wheat straw (combined). Pen sizes ranged from 6000 to 8000 m^2 with 200–280 heifers per pen for a stocking density of 30 m^2 per heifer. Pens were distributed across the feedlot separated by other pens or feeding alleyway. No two pens within the study were side by side and pens used for this study were based solely on availability. Manure was removed from the pens during spring 2019. Heifers were fed a grain-based ration as appropriate for their days on feed (DOF) twice per day and remained with their contemporary group throughout the study.

2.2. Behaviour recording

Heifer behaviour was recorded using the CowManager system which was attached to the Radio-frequency identification (RFID) tag (Allflex, Dallas, TX) that was in the proximal half of the right ear. The CowManager system is a 3-dimensional ear accelerometer that measures time ruminating, feeding, activity and inactivity through ear movements. Data from the sensor was collected every minute and averaged on an hourly basis for the period of time the heifers were at the feedlot. The working frequency of the CowManager tags is 2.4 GHz.

2.3. DD lesion assessment

2.3.1. Training programme

Prior to DD lesion assessment, three observers completed a training programme comparable to that developed by Gibbons et al. (2012) and consisted of using digital coloured photographs to illustrate DD lesions and M-stages. M-stages describe DD lesions based on morphological changes in the lesion over time. Each observer received a reference table and photographs of 30 lesions to score. Three and seven days later each observer scored the 30 lesions again. These scores were used to evaluate inter-observer agreement. Three additional training sessions using 30 photographs of different lesions each time, were conducted.

2.3.2. Pen walks

Direct observations were completed during biweekly pen walks by the three trained observers. Heifers were accustomed to pen walks and human presence as feedlot personnel completed daily health checks through pen walks. While heifers roamed freely in their pens, both hind feet of each heifer were observed between the heel bulbs for the presence or absence of a DD lesion. Lesions were scored using the M-stage scoring system (Fig. 1) developed by Döpfer et al. (1997) and modified by Berry et al. (2012). Observers ensured there was a direct line of sight to both hind feet and if needed binoculars (Nikon PROSTAFF 3S, Nikon Canada Inc., Mississauga, Ontario) were used to zoom in on feet. DD lesions were classified as M0 if the digital skin was normal with no lesions; M1 for an ulcerative lesion <2 cm; M2 for an ulcerative lesion >2 cm; M3 for lesions in the healing stage covered by a scab; M4 for lesions in the chronic stage showing dyskeratosis or surface proliferation; or M4.1 if a chronic stage lesion also had a small ulceration. Next, gait was observed, and a lameness score assigned using ZINPRO's Step-Up Locomotion Scoring system (Larson et al., 2014) for beef cattle. Heifers were assigned a score of 0 for normal (walks normally with no deviation in gait); 1 for mild lameness (shortened stride, dropping the head slightly, no limp when walking); 2 for moderate lameness (limp is detected when walking, limb still bears weight, slight head bob when walking); or 3 for severe lameness (no weight is applied to the affected limb, head dropped and back arched with head bob).

2.3.3. Detailed foot examination

Any heifer that presented a DD lesion or lameness during pen walks was selected for detailed foot examination. Further, all heifers were subject to detailed foot examination prior to being transported to the abattoir. Detailed foot examinations were done in a squeeze chute. One hind foot was lifted and secured with a rope, washed using a brush and water then dried with paper towel to remove any dirt present. The foot was then inspected between the heel bulbs and assigned a M-stage score. This process was then repeated for the other hind foot. Two observers scored all heifers and a consensus M-stage score recorded. Digital photographs of DD lesions were captured for future reference and where there was a difference in opinion of M-stage score the digital photograph of the lesion in question was scored by the experienced researcher who has extensive practice scoring claw lesions in cattle.

2.4. Data management

Microsoft Excel spreadsheets generated by the CowManager system were combined in Microsoft Access. To ensure accurate representation of behaviour throughout a day, 16 days that had less than 1400 min (97%) of behaviour recorded, were removed from the data set. For heifers with multiple DD identification days, only the first occurrence was kept for inclusion in the analysis. Additionally, only pens with heifers that developed DD were included and heifers within those pens with no lesions were classified as DD absent. Hourly data for each behaviour was converted to percent time per day ((daily minutes / total minutes) * 100).

Two variables were created from the DD lesion assessment data. A

Fig. 1. Images of feet (beef heifers) scored using the M-stage scoring system for digital dermatitis (DD) lesions (Döpfer et al., 1997; Berry et al., 2012). M0 represents absence of DD lesion. M1, M2 and M4.1 represent active DD lesions (ulcerative). M3 and M4 represents chronic DD lesions (healing stage covered by a scab, dyskeratosis or surface proliferation). Colour version available online.

dichotomous variable was created by assigning all heifers with an M0 score on both hind feet DD absent and DD present to those assigned any other M-stage score on one or both hind feet. Some DD M-stages had low frequencies; therefore, another variable was created which collapsed DD M-stages based on the hierarchy M2 > M4.1 > M1 > M4 > M3 (Relun et al., 2011). Heifers with an M0 score on both hind feet were coded DD absent; those having an M1, M2 or M4.1 score on one or both hind feet were coded active DD; and those having an M3 or M4 score on both hind feet or on one hind foot with an M0 score on the other hind foot were coded chronic DD (Table 1). For example, if a heifer had an M2 lesion in one hind foot and an M4 lesion in the other hind foot she was coded active DD.

Our study was designed to quantify behaviour 5 days before a detailed foot examination. However, 1 day before detailed foot examination heifers were removed from their pens and temporarily housed in a pen close to the squeeze chute. Consequently, behaviours on those days were not representatively of a typical day in their home pen. Thus, 1 day before and day of examination were removed from the data set and the period analysed was 5–2 days before detailed foot examination. The final data set included behaviour data for 84 heifers which included 48 calves and 36 yearlings (Fig. 2).

Table 1
Classification system used to group beef heifers into digital dermatitis (DD) categories.

M-stage score assigned[a]		
Hind Foot 1	Hind Foot 2	DD Classification
M0	M0	DD absent
M1 or M2 or M3 or M4 or M4.1	M0	DD present
M1 or M2 or M3 or M4 or M4.1	M1 or M2 or M3 or M4 or M4.1	DD present
M1 or M2 or M4.1	M0	Active DD
M1 or M2 or M4.1	M1 or M2 or M4.1	Active DD
M1 or M2 or M4.1	M3 or M4	Active DD
M0	M3 or M4	Chronic DD
M3 or M4	M3 or M4	Chronic DD

[a] According to Döpfer et al. (1997) and Berry et al. (2012); both hind feet are assigned a M-stage score.

2.5. Statistical analyses

Descriptive statistics were calculated to summarise behaviour using heifer as the experimental unit. All statistical analyses were conducted

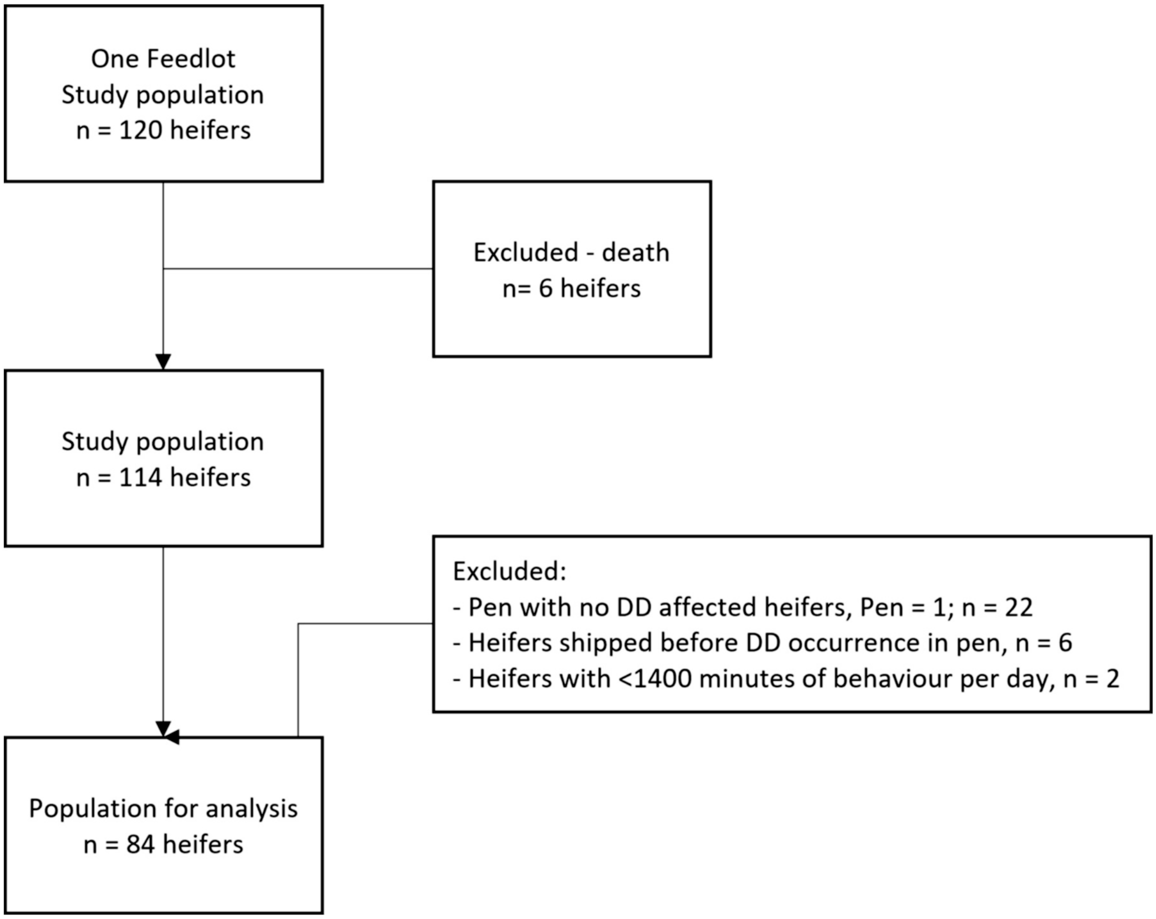

Fig. 2. Flowchart of final heifer selection for digital dermatitis (DD) in feedlot cattle study.

using IBM SPSS Statistics for Windows, version 26 (IBM Corp., Armonk, N.Y., USA) and a P value < 0.05 was considered statistically significant, whereas a P value from 0.05 to 0.10 was considered a tendency. In cases of multiple comparisons, a Bonferroni correction was applied. Model building was similar for all behaviours. As placement season, type (calves vs yearlings), arrival weight, pen, DOF, average daily gain (ADG), treatment, inspection weight, and lameness score varied among heifers the first step was to assess for multicollinearity between independent variables. If multicollinearity was present the predictor variable that was categorical or had the least number of missing observations was used. Continuous predictor variables (arrival weight, DOF, ADG and inspection weight) were tested for linearity. Next, a repeated measures analysis including all predictor variables as covariates was conducted to test effect modification. Higher-order (three-way) interactions were assessed using Restricted Maximum Likelihood (RMLE) and if significant remained in the model. Backward elimination was performed, and significant covariates remained in the model. If confounding was present (i.e., removing any variable changes the estimate of any other significant predictor by $\geq$30%), that variable remained in the model. Finally, a Two-Way Mixed ANOVA omitting covariates was performed. The best model was assessed using Akaike Information Criterion (AIC) value.

A stepwise approach was used to assess model assumptions for all behaviours separately. Outliers in the data were assessed graphically using boxplots. Normality of data distributions were assessed using the Shapiro-Wilk's test. Homogeneity of variances were evaluated by Levene's test of homogeneity of variance and homogeneity of covariances calculated by Box's test of equality of covariance matrices. If the variance of the differences between groups was equal, sphericity was assumed otherwise an epsilon (ε) correction was applied by adjusting the degrees of freedom used in calculating the P value.

3. Results

3.1. Inter-observer agreement

Kendall's W determined a statistically significant inter-observer agreement in the observer's assessments of DD lesion severity, $W = 0.72$, $P < 0.001$. Throughout the study the level of agreement was assessed six times and observers always agreed ($W = 0.72$ to $W = 0.77$, $P < 0.001$). Observers also remained in agreement when the 5-point M-stage scoring system was condensed into a simplified 3-point system; (DD absent, active DD and chronic DD), $W = 0.76$ to $W = 0.81$, $P < 0.001$.

3.2. DD lesion assessment

Of the 84 heifers included in the final analysis, 33 were scored as DD absent (M0) and 51 as DD present (M1, M2, M3, M4 or M4.1). Among DD affected heifers, 61% had DD on at least 1 hind foot and 39% had DD in both hind feet. Using lesion hierarchy, 26 heifers were classified as having active DD lesions and 25 heifers as having chronic DD lesions. Lesion M-stages (no lesion, active DD, or chronic DD) were distributed proportionately across pens and pen had no effect on heifer behaviour.

3.3. Behaviour: DD absent vs DD present

Daily mean percent time by behaviour is reported in Table 2. Five to two days prior to detailed foot examination, heifers with DD spent 3% less time per day ruminating ($F_{1,\ 107} = 7.41$, $P = 0.008$) and 3% more time inactive ($F_{1,\ 107} = 4.56$, $P = 0.04$) compared to those without DD. Heifers with DD spent less time ruminating and more time being inactive

Table 2
Mean percent time ruminating, feeding, inactivity (lying or standing) and activity (walking or movement) in beef heifers 5–2 days before detailed foot examination for digital dermatitis (DD), N = 84.

	Rumination Time (%)	Feeding Time (%)	Inactivity Time (%)	Activity Time (%)
M-stage[a]	Mean[b] ± SE 95% CI	Mean[b] ± SE 95% CI	Mean[b] ± SE 95% CI	Mean[b] ± SE 95% CI
DD absent	19.3 ± 0.7 (17.9–20.7)[c]	2.4 ± 0.2 (2.0–2.8)	46.1 ± 0.9 (44.4–47.9)[c]	32.2 ± 0.7 (30.9–33.6)
DD present	16.3 ± 0.8 (14.6–17.9)[d]	2.0 ± 0.2 (1.5–2.4)	49.0 ± 1.1 (46.9–51.1)[d]	32.8 ± 0.8 (31.2–34.5)

[a] According to Döpfer et al. (1997) and Berry et al. (2012) M-stage scoring system: DD absent (M0) and DD present (M1 to M4.1 inclusive).
[b] Estimated Marginal Means.
[c,d] Means with different letters within a column differ at $P < 0.05$.

than heifers without DD on specific days (Fig. 3). There was no significant interaction between Day and M-stage (DD absent and DD present) on rumination time ($P = 0.53$), feeding time ($P = 0.64$), inactivity time ($P = 0.45$) or activity time ($P = 0.54$).

3.4. Behaviour: DD absent vs active DD vs chronic DD

Daily mean percent time by M-stage is reported in Table 3. There was a statistically significant interaction between Day and M-stage (DD absent, active DD and chronic DD) on rumination time ($F_{6,\ 315} = 2.31$, $P = 0.03$). Overall, heifers with active DD lesions ruminated 5% less per day ($F_{1,\ 105} = 12.42$, $P = 0.002$) compared to heifers that did not have DD. No difference in rumination time was detected between heifers that did not have DD and heifers with chronic DD lesions ($P = 0.41$) or between heifers that had active DD and chronic DD lesions ($P = 0.18$). There was a tendency for daily feeding time to change by Day ($F_{5.27,\ 268.90} = 2.03$, $P = 0.07$, $\varepsilon = 0.88$) however, there was no difference in feeding time between M-stages ($P = 0.19$). Inactivity time did not change by Day ($P = 0.35$) however, there was a difference in inactivity time between M-stages ($F_{2,\ 105} = 3.15$, $P = 0.047$). Pairwise comparison between M-stages found no significant difference, however there was a tendency for heifers with active DD lesions to differ from heifers without DD in inactivity time ($P = 0.06$). Inactivity was greatest among heifers with active DD lesions (50.3% ± 1.4 SE) followed by those with chronic DD lesions (47.6% ± 1.6 SE) and finally heifers without DD (46.1% ±

Table 3
Mean percent time ruminating, feeding, inactivity (lying or standing) and activity (walking or movement) by M-stage in beef heifers 5–2 days before detailed foot examination for digital dermatitis (DD), N = 84.

	Rumination Time (%)	Feeding Time (%)	Inactive Time (%)	Active Time (%)
M-stage[a]	Mean[b] ± SE 95% CI	Mean[b] ± SE 95% CI	Mean[b] ± SE 95% CI	Mean[b] ± SE 95% CI
DD absent	19.3 ± 0.7 (17.9–20.7)[c]	2.4 ± 0.2 (2.0–2.8)	46.1 ± 0.9 (44.4–47.9)[e]	32.2 ± 0.7 (30.9–33.6)
Active DD	14.6 ± 1.1 (12.4–16.8)[d]	1.8 ± 0.3 (1.1–2.4)	50.3 ± 1.4 (47.5–53.1)[f]	33.4 ± 1.1 (31.2–35.7)
Chronic DD	18.1 ± 1.3 (15.5–20.6)[c,d]	2.4 ± 0.4 (1.6–3.1)	47.6 ± 1.6 (44.4–50.8)[e,f]	32.1 ± 1.3 (29.5–34.7)

[a] According to Döpfer et al. (1997) and Berry et al. (2012) M-stage scoring: DD absent (M0); Active DD (M1, M2 & M4.1); Chronic DD (M3 & M4).
[b] Estimated Marginal Means.
[c,d] Means with different letters within a column differ at $P < 0.05$.
[e,f] Means with different letters within a column differ at $P < 0.10$.

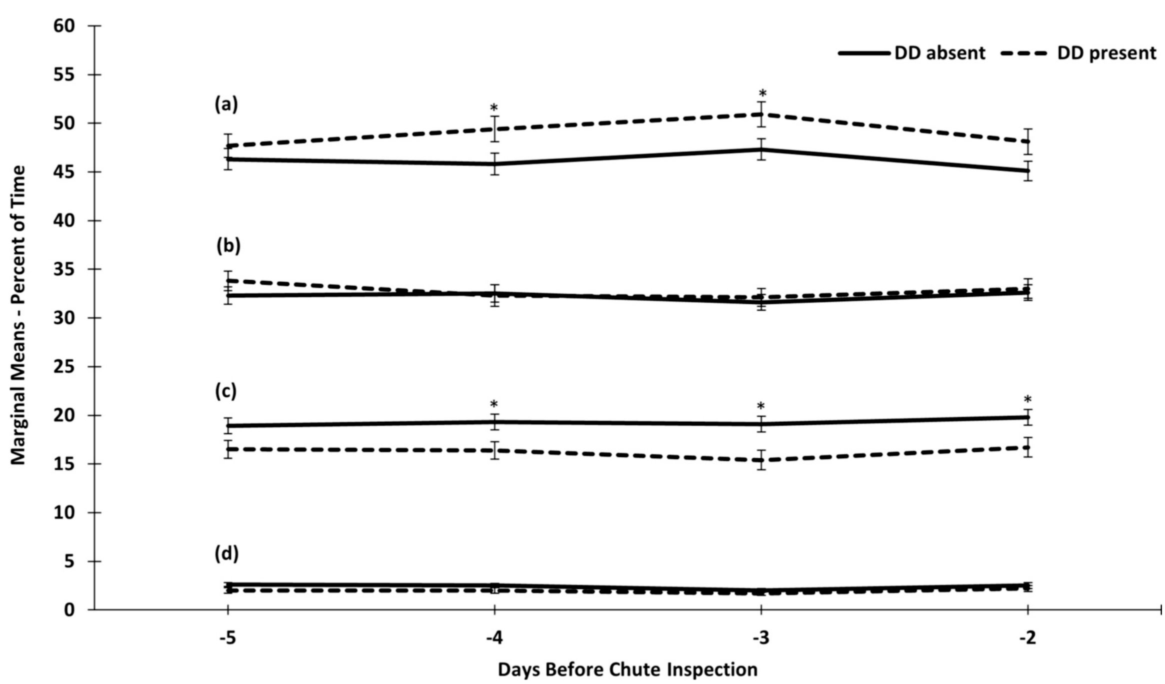

Fig. 3. Behaviour pattern for beef heifers (digital dermatitis (DD) absent; n = 33 and DD present; n = 51) 5–2 days before detailed foot examination as a percentage of 24-hour periods ± SE. (a) Mean percent time inactive per day; (b) Mean percent time active per day; (c) Mean percent time ruminating per day; (d) Mean percent time feeding per day. Means with an asterisk (*) are significantly different; $P < 0.05$.

0.9 SE). There was no interaction between Day and activity time ($P = 0.80$) nor among M-stages ($P = 0.64$).

4. Discussion

To the best of our knowledge this is the first report quantifying behaviour of DD affected beef heifers. On average, rumination time was significantly less in DD affected heifers with overall averages similar to those published for finishing beef steers consuming different rations (Gentry et al., 2016). Pavlenko et al. (2011) is the only study that has reported rumination time in DD affected dairy cows and they reported no difference in overall rumination time between DD affected and healthy dairy cows. In that study, rumination time was observed 2–6 weeks after claw trimming and footbath treatment and each cow was observed twice for a total of 120 min between milking sessions. This likely explains the difference in results as our study measured rumination over a 24-hour period, our heifers did not receive a footbath treatment and we observed the period before not after DD identification and treatment. Decreased time spent ruminating has also been associated with early detection of BRD and lameness in beef cattle before onset of clinical signs (Marchesini et al., 2018). In our study, time spent ruminating was lower for heifers with active DD lesions compared to DD absent heifers likely due to pain and discomfort caused by the ulcerative nature of active DD lesions. Digital dermatitis lesions can be painful during the active stages (Cutler et al., 2013) and rumination decreases when animals are in pain as observed in cattle after dehorning (Sylvester et al., 2004), castration (Ting et al., 2003) and liver biopsy taking (Beausoleil and Stafford, 2012).

Our heifers spent on average about 48% of their time being inactive, which includes lying and standing time. Unlike other studies we are unable to distinguish between lying and standing as the CowManager system cannot make that distinction thus limiting our ability to make direct comparisons. Mean percentage lying times of 48.5% (Robért et al., 2011) and 49.8% (Hoffman and Self, 1973) have been reported in feedlot steers. Our averages are lower and include time spent standing. We believe this probably reflects the difference in sex, housing, management, environmental conditions, and data collection tool. Our heifers were observed within a commercial feedlot pen and subjected to all management protocols whereas the other studies conducted small pen trials that removed instances of human interaction and did not reflect the effect of behaviour in large pens (Hoffman and Self, 1973; Robért et al., 2011). Inactivity in cattle can be influenced by the physical environment (Graunke et al., 2011; Lee et al., 2013) and our heifers were exposed to different seasons, snowstorms, and wet pens. In our study DD affected heifers spent more time being inactive when compared to the DD absent heifers. This could be because DD affected animals have a lesion between the heel bulbs which causes discomfort and reduces movement (Flower and Weary, 2006, 2009). Heifers with active DD lesions spent more time being inactive compared to heifers without DD lesions, possibly due to the pain arising from ulcerative lesions during movement. Somers (2004) showed that dairy animals with active DD lesions in both hind feet had reduced total lying time and increased standing time when compared to animals with no lesions.

Feeding time did not differ between DD affected heifers and those without DD lesions however there was a tendency for feeding time to change over time. These results were surprising since we hypothesised that heifers with DD would have spent less time feeding knowing that feeding time is decreased in dairy cattle with health disorders (González et al., 2008; Huxley, 2013; Daros et al., 2020). Additionally, we expected to observe a difference in feeding time since we observed a difference in rumination time and rumination is known to be correlated to feeding time (Schirmann et al., 2012). Unlike with other health disorders animals with DD do not present with a fever or loss of appetite which might be a possible reason why we found no difference in time spent feeding between heifers with DD and those without DD. Lameness a clinical sign of DD could also affect feeding time. In our study, of the heifers with DD less than 20% presented with lameness where a limp was detected when walking suggesting that the capacity of our heifers to stand and feed may not have hampered. Our results, acknowledging study design differences, were similar to that of Somers (2004) and Pavlenko et al. (2011) who found no difference in total feeding time between DD affected animals and those without DD lesions.

Heifers did not differ in activity level. This might be because feedlot cattle are in general not very active animals (Ray and Roubicek, 1971) and activity is known to decrease in feedlot cattle as they get heavier (Park et al., 2020). Many heifers in this study were identified with DD at finishing close to transport to the abattoir. At that time in the feeding cycle, heifers are very heavy and most activity is limited to feeding and drinking. Additionally, pen density is increased which can influence cattle movement and pen conditions (mud condition) as shown by Mader and Colgan (2007). Although animal management differed between this study and that by Pavlenko et al. (2011), they also reported no difference in activity (walking, grooming, or exploring) time between DD affected and DD absent animals. As with inactivity, we are unable to separate contributing variables from our activity data to make direct comparisons.

Traditionally, whenever behaviour is used as an early indicator for disease, the critical period for analysis includes the exact date of disease onset. For this study, heifers were observed for DD biweekly which means our precision is limited to a 2-week window in which heifers could have gone through different M-stages. Therefore, a major limitation to our study was identification of DD lesions at disease onset. Even with biweekly pen walks most DD cases were identified during detailed foot examinations in the chute. Although our results show differences in both populations prior to detailed foot examination, we would require more precise information on disease onset to make recommendations for early detection. We also believe not being able to precisely identify disease onset may be the reason we were unable to delineate differences between heifers without DD and those with chronic DD lesions and heifers with active DD compared to those with chronic DD. Additionally, rumination, feeding, inactivity and activity behaviours in cattle are sensitive to factors other than illness, such as diet, dry matter intake, days on feed, body weight and stress (Mitlöhner et al., 2002; Gentry et al., 2016), hence heifers who spend less time ruminating and more time inactive may not have DD.

With only one feedlot and a small number of heifers (n = 84) there is limited external validity to our findings. It is likely that these behaviour variables will differ among herds managed differently but provide a good reference for differences observed between health status of comparable animals under the same management. Our results re-emphasise how difficult DD detection is for feedlots and the benefits that could be derived from using sensors to monitor behaviour patterns especially in situations when change in behaviour is subtle.

5. Conclusion

This is the first report in North America to describe the impact of DD on the behaviour of feedlot cattle. Behaviour variables were established based on measurements from an ear accelerometer and DD M-stage assigned during pen walks and at detailed foot examinations. Heifers with DD spent significantly less time ruminating and more time inactive compared to heifers without lesions 5–2 days before detailed foot examination. Finally, changes in time spent ruminating and inactivity is associated with DD in feedlot cattle with significant differences among DD M-stages. Our results increase scientific knowledge on the impact of DD on the behaviour of beef heifers, information that is necessary for the development of strategies for early detection and diagnosis of DD.

Declaration of Competing Interest

There are no conflicts of interest associated with this publication.

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References

Beausoleil, N.J., Stafford, K.J., 2012. Is a nonsteroidal anti-inflammatory drug required to alleviate pain behavior associated with liver biopsy in cattle? J. Vet. Behav. 7 (4), 245–251. https://doi.org/10.1016/j.jveb.2011.09.001.

Berry, S.L., Read, D.H., Famula, T.R., Mongini, A., Döpfer, D., 2012. Long-term observations on the dynamics of bovine digital dermatitis lesions on a California dairy after topical treatment with lincomycin HCl. Vet. J. 193 (3), 654–658. https://doi.org/10.1016/j.tvjl.2012.06.048.

Berry, S.L., Read, D.H., Walker, R.L., Famula, T.R., 2010. Clinical, histologic, and bacteriologic findings in dairy cows with digital dermatitis (footwarts) one month after topical treatment with lincomycin hydrochloride or oxytetracycline hydrochloride. J. Am. Vet. Med. Assoc. 237 (5), 555–560. https://doi.org/10.2460/javma.237.5.555.

Brown, C.C., Kilgo, P.D., Jacobsen, K.L., 2000. Prevalence of papillomatous digital dermatitis among culled adult cattle in the southeastern United States. Am. J. Vet. Res. 61 (8), 928–930. https://doi.org/10.2460/ajvr.2000.61.928.

Cheli, R., and Mortellaro, C., 1974, Digital dermatitis in beef cattle. 8th International Conference on Disease of Cattle. p 208–213, Milan, Italy.

Cutler, J.H.H., Cramer, G., Walter, J.J., Millman, S.T., Kelton, D.F., 2013. Randomized clinical trial of tetracycline hydrochloride bandage and paste treatments for resolution of lesions and pain associated with digital dermatitis in dairy cattle. J. Dairy Sci. 96 (12), 7550–7557. https://doi.org/10.3168/jds.2012-6384.

Daros, R.R., Eriksson, H.K., Weary, D.M., von Keyserlingk, M.A.G., 2020. The relationship between transition period diseases and lameness, feeding time, and body condition during the dry period. J. Dairy Sci. 103 (1), 649–665. https://doi.org/10.3168/jds.2019-16975.

Döpfer, D., Koopmans, A., Meijer, F.A., Schukken, Y.H., Szakáll, I., Klee, W., Bosma, R.B., Cornelisse, J.L., van Asten, A.J.A.M., ter Huurne, A.A.H.M., 1997. Histological and bacteriological evaluation of digital dermatitis in cattle, with special reference to spirochaetes and Campylobacter faecalis. Vet. Rec. 140 (24), 620–623. https://doi.org/10.1136/vr.140.24.620.

Flower, F.C., Weary, D.M., 2006. Effect of hoof pathologies on subjective assessments of dairy cow gait. J. Dairy Sci. 89 (1), 139–146. https://doi.org/10.3168/jds.S0022-0302(06)72077-X.

Flower, F.C., Weary, D.M., 2009. Gait assessment in dairy cattle. Animal 3 (1), 87–95. https://doi.org/10.1017/S1751731108003194.

Gentry, W.W., Weiss, C.P., Meredith, C.M., McCollum, F.T., Cole, N.A., Jennings, J.S., 2016. Effects of roughage inclusion and particle size on performance and rumination behavior of finishing beef steers1. J. Anim. Sci. 94 (11), 4759–4770. https://doi.org/10.2527/jas.2016-0734.

Gibbons, J., Vasseur, E., Rushen, J., de Passille, A.M., 2012. A training programme to ensure high repeatability of injury scoring of dairy cows. Anim. Welf. 21, 379–388. https://doi.org/10.7120/09627286.21.3.379.

González, L.A., Tolkamp, B.J., Coffey, M.P., Ferret, A., Kyriazakis, I., 2008. Changes in feeding behavior as possible indicators for the automatic monitoring of health disorders in dairy cows. J. Anim. Sci. 91 (3), 1017–1028. https://doi.org/10.3168/jds.2007-0530.

Graunke, K.L., Schuster, T., Lidfors, L.M., 2011. Influence of weather on the behaviour of outdoor-wintered beef cattle in Scandinavia. Livest. Sci. 136 (2), 247–255. https://doi.org/10.1016/j.livsci.2010.09.018.

Hesseling, J., Legione, A.R., Stevenson, M.A., McCowan, C.I., Pyman, M.F., Finochio, C., Nguyen, D., Roic, C.L., Thiris, O.L., Zhang, A.J., van Schaik, G., Coombe, J.E., 2019. Bovine digital dermatitis in Victoria, Australia. Aust. Vet. J. 97 (10), 404–413. https://doi.org/10.1111/avj.12859.

Hoffman, M.P., Self, H.L., 1973. Behavioral traits of feedlot steers in Iowa. J. Anim. Sci. 37 (6), 1438–1445. https://doi.org/10.2527/jas1973.3761438x.

Huxley, J.N., 2013. Impact of lameness and claw lesions in cows on health and production. Livest. Sci. 156 (1), 64–70. https://doi.org/10.1016/j.livsci.2013.06.012.

van Huyssteen, M., Barkema, H.W., Mason, S., Orsel, K., 2020. Association between lameness risk assessment and lameness and foot lesion prevalence on dairy farms in Alberta, Canada. J. Dairy Sci. 103 (12), 11750–11761. https://doi.org/10.3168/jds.2019-17819.

Krull, A.C., Shearer, J.K., Gorden, P.J., Scott, H., Plummer, P.J., 2016. Digital dermatitis: Natural lesion progression and regression in Holstein dairy cattle over 3 years. J. Dairy Sci. 99 (5), 3718–3731. https://doi.org/10.3168/jds.2015-10535.

Kulow, M., Merkatoris, P., Anklam, K.S., Rieman, J., Larson, C., Branine, M., Dopfer, D., 2017. Evaluation of the prevalence of digital dermatitis and the effects on performance in beef feedlot cattle under organic trace mineral supplementation. J. Anim. Sci. 95 (8), 3435–3444. https://doi.org/10.2527/jas.2017.1512.

Larson, C., Tomlinson, D., Branine, M., Mulling, C., Dopher, D., Edwards, T., 2014. Cattle lameness: identification, prevention and control of claw lesions. Produced by the Zinpro Corporation International Bovine Lameness Committee, First ed..,. Zinpro Corporation.

Lee, C., Fisher, A.D., Colditz, I.G., Lea, J.M., Ferguson, D.M., 2013. Preference of beef cattle for feedlot or pasture environments. Appl. Anim. Behav. Sci. 145 (3), 53–59. https://doi.org/10.1016/j.applanim.2013.03.005.

Mader, T.L., Colgan, S.L., 2007. Pen density and straw bedding during feedlot finishing. Neb. Beef Cattle Rep. 70, 43–46 https://digitalcommons.unl.edu/animalscinbcr/70.

Marchesini, G., Mottaran, D., Contiero, B., Schiavon, E., Segato, S., Garbin, E., Tenti, S., Andrighetto, I., 2018. Use of rumination and activity data as health status and performance indicators in beef cattle during the early fattening period. Vet. J. 231, 41–47. https://doi.org/10.1016/j.tvjl.2017.11.013.

Mitlöhner, F.M., Galyean, M.L., McGlone, J.J., 2002. Shade effects on performance, carcass traits, physiology, and behavior of heat-stressed feedlot heifers1. J. Anim. Sci. 80 (8), 2043–2050. https://doi.org/10.1093/ansci/80.8.2043.

Naaktgeboren, K.M., Hansen, S., Oliver, K., 2017. Comparative study on efficacy of cow manager technology. Honors Project. Department of Animal Science, Iowa State University, Ames, IA.

Orsel, K., Plummer, P., Shearer, J., Buck, J.D., Carter, S.D., Guatteo, R., Barkema, H.W., 2018. Missing pieces of the puzzle to effectively control digital dermatitis. Transbound. Emerg. Dis. 65 Suppl 1, 186–198. https://doi.org/10.1111/tbed.12729.

Park, R.M., Schubach, K.M., Cooke, R.F., Herring, A.D., Jennings, J.S., Daigle, C.L., 2020. Impact of a cattle brush on feedlot steer behavior, productivity and stress physiology. Appl. Anim. Behav. Sci. 228, 104995 https://doi.org/10.1016/j.applanim.2020.104995.

Pavlenko, A., Bergsten, C., Ekesbo, I., Kaart, T., Aland, A., Lidfors, L., 2011. Influence of digital dermatitis and sole ulcer on dairy cow behaviour and milk production. Animal 5 (8), 1259–1269. https://doi.org/10.1017/S1751731111000255.

Ray, D.E., Roubicek, C.B., 1971. Behavior of feedlot cattle during two seasons. J. Anim. Sci. 33 (1), 72–76. https://doi.org/10.2527/jas1971.33172x.

Read, D.H., Walker, R.L., 1998. Papillomatous digital dermatitis (footwarts) in california dairy cattle: clinical and gross pathologic findings. J. Vet. Diagn. Invest. 10 (1), 67–76 https://doi.org/10.1177%2F104063879801000112.

Relun, A., Guatteo, R., Roussel, P., Bareille, N., 2011. A simple method to score digital dermatitis in dairy cows in the milking parlor. J. Dairy Sci. 94 (11), 5424–5434. https://doi.org/10.3168/jds.2010-4054.

Richeson, J.T., Lawrence, T.E., White, B.J., 2018. Using advanced technologies to quantify beef cattle behavior. Transl. Anim. Sci. 2 (2), 223–229. https://doi.org/10.1093/tas/txy004.

Robért, B.D., White Bj Fau - Renter, D.G., Renter Dg Fau - Larson, R.L., Larson, R.L., 2011. Determination of lying behavior patterns in healthy beef cattle by use of wireless accelerometers. Am. J. Vet. Res. 72 (4), 467–473. https://doi.org/10.2460/ajvr.72.4.467.

Rutten, C.J., Velthuis, A.G.J., Steeneveld, W., Hogeveen, H., 2013. Invited review: sensors to support health management on dairy farms. J. Dairy Sci. 96 (4), 1928–1952. https://doi.org/10.3168/jds.2012-6107.

Schirmann, K., Chapinal, N., Weary, D.M., Heuwieser, W., von Keyserlingk, M.A.G., 2012. Rumination and its relationship to feeding and lying behavior in Holstein dairy cows. J. Dairy Sci. 95 (6), 3212–3217. https://doi.org/10.3168/jds.2011-4741.

Somers, J.G.C.J., 2004. Claw Disorders and Disturbed Locomotion in Dairy Cows: the Effect of Floor Systems and Implications for Animal Welfare. Utrecht University, Utrecht, The Netherlands. Doctoral dissertation.

Sylvester, S., Stafford, K., Mellor, D., Bruce, R., Ward, R., 2004. Behavioural responses of calves to amputation dehorning with and without local anaesthesia. Aust. Vet. J. 82 (11), 697–700. https://doi.org/10.1111/j.1751-0813.2004.tb12162.x.

Theurer, M.E., Amrine, D.E., White, B.J., 2013. Remote noninvasive assessment of pain and health status in cattle. Vet. Clin. North Am. Food Anim. Pract. 29 (1), 59–74. https://doi.org/10.1016/j.cvfa.2012.11.011.

Ting, S.T.L., Earley, B., Hughes, J.M.L., Crowe, M.A., 2003. Effect of ketoprofen, lidocaine local anesthesia, and combined xylazine and lidocaine caudal epidural anesthesia during castration of beef cattle on stress responses, immunity, growth, and behavior. J. Anim. Sci. 81 (5), 1281–1293. https://doi.org/10.2527/2003.8151281x.

Weary, D.M., Niel, L., Flower, F.C., Fraser, D., 2006. Identifying and preventing pain in animals. Appl. Anim. Behav. Sci. 100 (1), 64–76. https://doi.org/10.1016/j.applanim.2006.04.013.

Wolfger, B., Schwartzkopf-Genswein, K.S., Barkema, H.W., Pajor, E.A., Levy, M., Orsel, K., 2015a. Feeding behavior as an early predictor of bovine respiratory disease in North American feedlot systems. J. Anim. Sci. 93 (1), 377–385. https://doi.org/10.2527/jas.2013-8030.

Wolfger, B., Timsit, E., Pajor, E.A., Cook, N., Barkema, H.W., Orsel, K., 2015b. Technical note: Accuracy of an ear tag-attached accelerometer to monitor rumination and feeding behavior in feedlot cattle. J. Anim. Sci. 93 (6), 3164–3168. https://doi.org/10.2527/jas.2014-8802.