MONITORING GRAZING BEHAVIOR OF CATTLE WITH AN ACCELEROMETRY-BASED ACTIVITY MONITOR AND GPS

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ABSTRACT: Spatio-temporal information on the grazing behavior of animals can help farmers do the efficient management of the pasture and animals. For the purpose of establishing an easily monitoring system of grazing behaviors of cattle, we developed a simple method for discriminating the activity and location for eating from the other activities and locationsusing an accelerometry-based activity monitor, the Kenz Lifecorder (LCEX; Suzuken Co Ltd, Nagoya, Japan), combined with a global positioning system (GPS). The study was conducted in a mixed sown pasture (2.85 ha) located on a northeast slope (ca. 8.3°) ranging from 115 to 135 m above sea level. Four cows of 20 cows grazed in the pasture were fitted LCEX-GPS collars over the course of four days (June 14 to June 18, 2010) and were recorded the activity count and the location every 4 seconds and 1 minutes, respectively. We also observed behaviors of the four cows for 15 hours and classified the activities into eating, ruminating and resting every minute. Logistic regression (LR) and linear discriminant analysis (LDA) were applied to the dataset (LCEX and observation data) to distinguish eating and other activities (resting and ruminating). The LDA results showed a higher correct discrimination percentage for all cows (90.6 to 94.6%) than did the LR results (80.8 to 91.8%). Applying the LDA function over the whole period of LCEX data, the time spent eating averaged 443 to 475 minutes per day (30.7 to 33.0%). By using the locations obtained by the GPS collars, we determined the spatial distribution patterns of eating and other activities of cattle. During the daylight period, the cows mostly grazed in the lower-altitude area of the paddock, covering a wider area than at night. During the midnight, the cows spent most of their time in the higher-altitude area of the paddock, with less eating activity.

1. INTRODUCTION

Spatio-temporal information on the grazing behavior of animals can help farmers do the efficient management of the pasture and animals (Turner et al. 2000). Thus, the development of simple, cost-effective tools for timely monitoring of grazing cows would benefit herders and researchers.

A number of analysis tools have been developed to aid the collection of data on spatio-temporal changes in grazing behaviors. Global positioning systems (GPS), which record animal locations with high temporal frequency, have increasingly been used to monitor spatial distribution and track routes (Barbari et al. 2006; Ganskopp 2001; Ganskopp et al. 2000) and are often combined with sensing devices for monitoring animal activities, especially grazing behavior. Information on grazing behavior can be acquired from these devices by measuring the electrical resistance of jaw opening (Matsui and Okubo 1991; Penning 1983; Rutter 2000) or by pendulum pedometers fitted around the neck (Umemura et al. 2009), tilt sensors attached to a commercial GPS collar (Ganskopp, 2001), devices that record the sounds of bites and chews in grazing (Ungar and Rutter 2006) and accelerometers fitted on the jaw or neck (Moreau et al. 2009; Watanabe et al. 2008). However, most of these devices cannot be used by farmers because they are capable taking measurements for only a few days due to their high energy consumption or because they are expensive and require extensive experience to attach them to animals (Ungar and Rutter 2006). Moreover, the data obtained by such sensing devices are complicated, and the classification of grazing behavior requires specific analysis software, such as the “Graze” program (Rutter 2000).

Recently, simple accelerometry-based activity monitors have been developed for studies of human health (Kumahara et al. 2004; McClain et al. 2007). Although these devices convert raw accelerometer data into an activity level and output by the criteria considered in each proprietary subtly different human activity, they can be used for animal behavior studies that include data processing and analysis. Ueda et al. (2011) developed a simple method for identifying the eating activity of dairy cows in flatland pasture using the Kenz Lifecorder EX (LCEX; Suzuken Co Ltd, Nagoya, Japan), which has recently been developed into a commercially available tool for management of and research on human health at a relatively low price (approximately 430 US dollars per unit). Ueda et al. processed the data obtained from the device with linear discriminant analysis (LDA) and succeeded in identifying the eating activity of cows in pasture with a correct discrimination score of 94.5%. The results suggest that an accelerometry-based activity monitor is a useful tool for identifying the activities of cows in pasture and that the LCEX system allows for the easy measurement of eating time and facilitates determining the pattern of eating activity of cows grazing on pasture. However, for the further development of cow activity monitoring using the device, we needed to test the LCEX system and LDA in a pasture with a heterogeneous environment, especially slope pasture, because most grazed pasture in Japan is located on mountainous or hilly land. Moreover, in conjunction with GPS location information, it is expected that spatial information on cow grazing behavior can be obtained easily and cost-effectively.

The aim of this study was to develop a statistical method for classifying the eating activity from other activities using the data obtained by LCEX and to monitor spatio-temporal changes in the eating activities of grazing cows in conjunction with GPS collar placement. In the present study, logistic regression (LR) and an LDA function analysis (Fisher 1936) were attempted for the classification, which have been frequently used for animal activity pattern classification (Schleisner et al. 1999; Ungar et al. 2011). And using the estimated eating activity data and the GPS location data, we created the spatial pattern map in the eating and other activities in the paddock.

2. MATERIALS AND METHODS

2.1 Study site

The study was conducted in a mixed sown pasture (2.85 ha) located on a northeast slope (115-135 m above sea level) at the National Agricultural Research Center for Hokkaido Region (42°59'N, 141°24'E) (Figure 1a). The pasture was established in the 1960s by sowing orchardgrass (*Dactylis glomerata* L.), tall fescue (*Festuca arundinacea* Schreb.), meadow fescue (*Festuca pratensis* Huds.), Kentucky bluegrass (*Poa pratensis* L.), timothy (*Phleum pratense* L.), redtop (*Agrostis alba* L.) and white clover (*Trifolium repens* L.). This pasture has been used as grazing land for Japanese Black cattle without fertilizer application for the last ten years. We had previously divided the pasture into three paddocks of 1, 1 and 0.85 ha for a rotational grazing trial (Watanabe, unpublished), and the third paddock (0.85 ha) in the south end was used for the present study. In this paddock, twenty breeding Japanese Black cows and their five calves were stocked for four days during the period from 10:00 June 14 to 10:00 June 18, 2010.

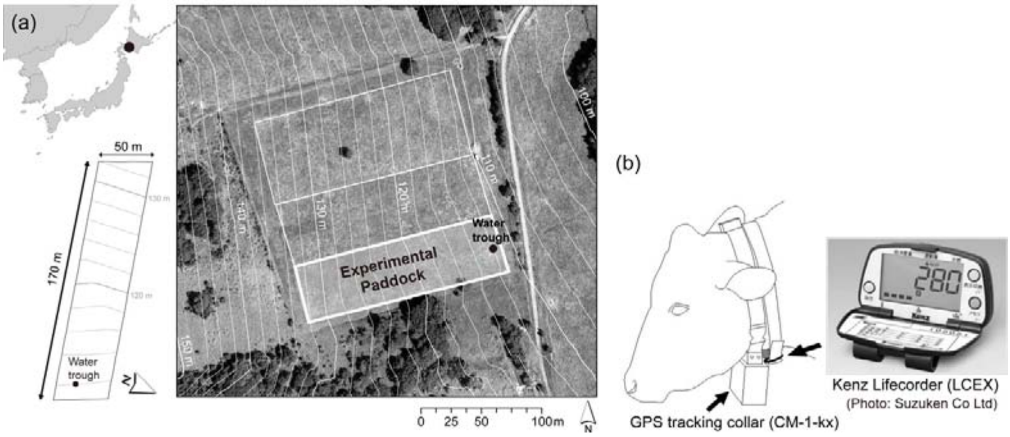


Figure 1. Location of the experimental paddock with 2-m contour (a), and an illustration showing a GPS collar and a small bag containing a LCEX accelerometer attached to a neck band (b).

2.2 Fitting GPS and LCEX to cow

We selected six cows (cow 1, 596 kg, 16 years old; cow 36, 516 kg, 6 years old; cow 50, 588 kg, 4 years old; cow 54, 458 kg, 3 years old; cow 62, 407 kg, 2 years old; and cow 63, 395 kg, 2 years old) from the 20 cows based on the balance for age and body weight. Each cow was fitted with a GPS collar (CM-10kx, Furuno Electric Co Ltd, Nishinomiya, Japan) that had a 12-channel GPS receiver that allowed the simultaneous use of signals from up to 12 satellites and a collar attached to a small fabric bag containing an LCEX. The LCEX was wrapped in a vinyl bag for waterproofing and placed within the small fabric bag (Figure 1b). During 4-day grazing periods, the positions of the cows were recorded every minute by the GPS collars.

The LCEX (weight, 60 g; width, 72.5 mm; height, 41.5 mm; thickness, 27.5 mm) is a single-axis accelerometer that measures acceleration at a rate of 32 samples per second and records a step count for humans and an intensity of physical activity at 11 scaled magnitudes, including 0 (no movement), 0.5 (subtle) and 1-9 (1, light; 9, vigorous) at 4-second intervals for 5 weeks. According to Kumahara et al. (2004) and McClain et al. (2007), an activity level of 0 (AL_0) indicates that the acceleration values are always less than 0.06 G during the 4-s sampling interval. However, AL_0.5 indicates that, although acceleration values above the minimum threshold (0.06 G) exist, these values were found for fewer than three pulses during the 4-s sampling interval. When the sensor detects three or more acceleration pulses in the 4-second interval, the activity is categorized from AL_1 (0.06 G) to AL_9 (1.94 G). The collected data can be easily downloaded to a computer for analysis using Kenz Physical Activity Analysis software ver. 1.0 (Suzuken Co Ltd, Nagoya, Japan).

2.3 Field observation of cows' grazing behavior

We recorded the behavior of four of six cows with attached LCEX and GPS monitors from June 16 to 18, 2010. In the 3-day field observation period, a total of 15 hours of grazing behavior data were obtained. Three observers monitored, and recorded cows' behavior (eating, ruminating or resting) every minute. The weather during this experiment was clear except for day 3; it rained a total of 26.5 mm between 14:00 June 16 and 4:00 June 17. The mean air temperature was 18.1ºC, and the maximum and minimum temperatures were 24.5ºC and 15.2ºC, respectively. The sunrise, meridian passage, and sunset times (GMT+9) at the experimental paddock were 3:52, 11:35 and 19:18, respectively.

2.4 Data processing

All data handling and discriminant analyses were performed using R statistical software, version 2.12.1 (R Development Core Team 2010). To match the interval of LCEX activity data with the GPS collar data-acquisition interval (1 min), the LCEX data was summed every minute. Using the 1-min interval data from the LCEX and field observations, LR and LDA were performed to distinguish between eating and other activities, which included ruminating and resting. To validate the accuracy of the LR and LDA functions, a bootstrap procedure with 10,000 iterations was applied, based on an independent test data set, as in Watanabe et al. (2008). For each iteration process, the data were randomly divided into training and test subsets in a proportion of two to one, respectively. Then, the training subset data were used to develop the LR and LDA functions. Finally, using the functions, classification accuracies of eating activities in the test subset data were calculated.

3. RESULTS

3.1 Eating activity

All LCEX and GPS collars successfully acquired scheduled records during the 4-day grazing periods. From the 15 hours of behavioral observation, 906 minutes of data were obtained for each cow, giving a total of 3,624 minutes of data (eating, ruminating, resting and others data were 1,123, 1,615, 757, 126 minutes, respectively). Figure 2 shows the histograms of the percent correct discrimination scores for eating in 10,000 bootstrap replicates using the LR and LDA functions. The threshold values in the LR results for each cow were larger (8.5-16.6 AL min^{-1}) than the LDA threshold values (7.8-10.4 AL min^{-1}). For the whole data set, the mean LR and LDA values (± SD) were 10.8 ± 0.2 and 8.9 ± 0.1, respectively. Overall, the LDA results showed a higher correct discrimination percentage for all cows (90.6 to 94.6%) than did the LR results (80.8 to 91.8%). Similarly, the correct discrimination percentages for LDA and LR on the whole data sets were 92.4% and 85.6%, respectively. These results indicate that the LDA function should be used to distinguish cow eating activity in the LCEX data.

3.2 Eating time

Applying the LDA function, the hourly pattern of eating activity (eating time per hour) was obtained for each cow (Figure 3), and Table 1 summarizes the cow eating time per day (min day^{-1}) and the percentage of time spent eating. Each cow primarily grazed during the daylight period, which started at sunrise and ended at sunset. The main periods of time that the cows spent on eating activity were after sunrise (4:00 to 5:00), before noon (10:00 to 12:00), and before sunset (16:00 to 20:00). Over the course of a day, the cows spent on average 443 to 475 minutes (30.7 to 33.0% per day) eating (Table 1).

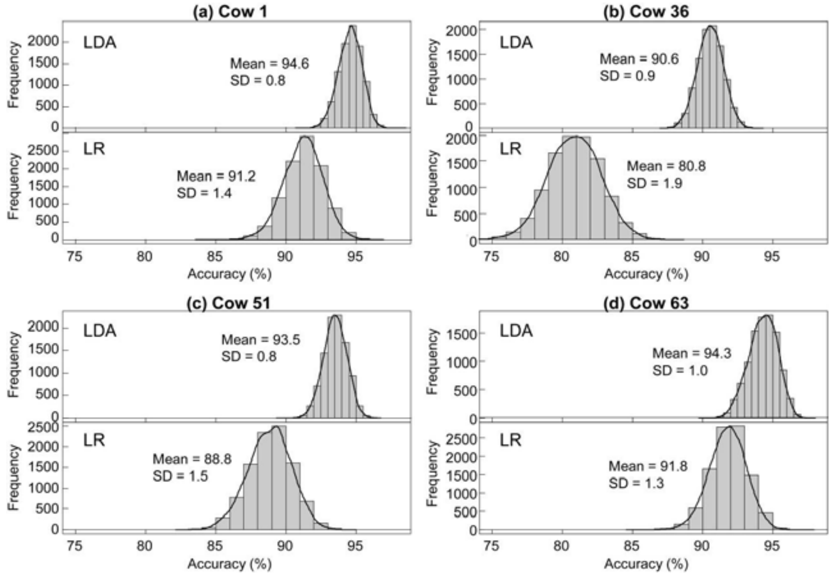


Figure 2. Histogram showing the percentage of correct answers obtained in the feeding activity of bootstrapping 10,000 times using logistic regression (LR) and linear discriminant analysis (LDA).

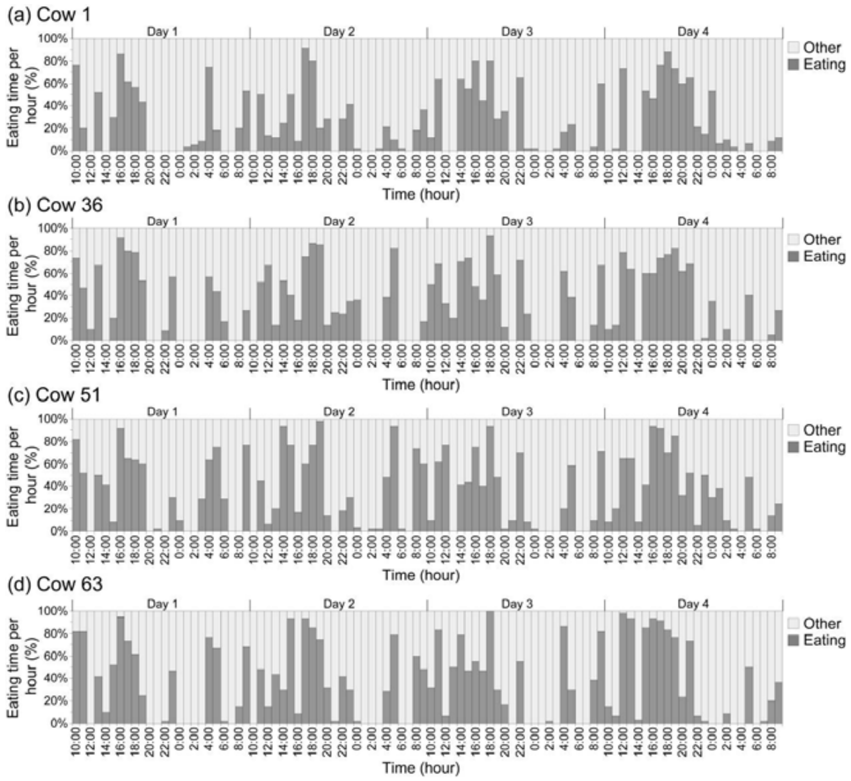


Figure 3. Hourly distributions of cow eating activity obtained from LCEX during a 4-day grazing experiment.

Table 1. The daily eating time for the results of LDA and the percentage per day for each cow.

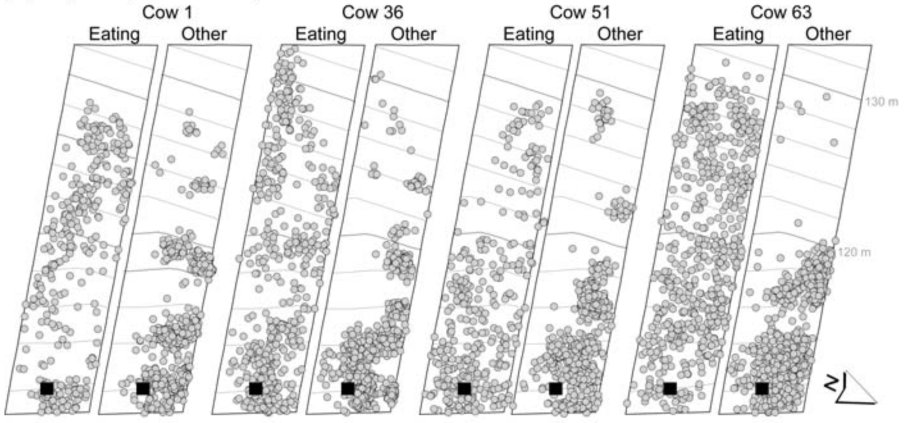
	Eating time by LCEX (min d^{-1}) and the percent per day (%)[1]			
Cow no.	Day 1	Day 2	Day 3	Day 4
1	366 (25.4%)	324 (22.5%)	381 (26.5%)	405 (28.1%)
36	437 (30.3%)	456 (31.7%)	503 (34.9%)	459 (31.9%)
51	496 (34.4%)	503 (34.9%)	445 (30.9%)	513 (35.6%)
63	479 (33.3%)	488 (33.9%)	503 (34.9%)	521 (36.2%)
Mean	445 (30.9%)	443 (30.7%)	458 (31.8%)	475 (33.0%)

[1] Eating time was predicted by using LDA functions.

3.3 Spatial distribution of eating and other activities during the day and night

Figure 4 shows the spatial distributions of the four cows during their time spent eating and in other activities during the daytime (9:00 to 15:00) and nighttime (21:00 to 3:00). During the daytime(Figure 4a), the cows mostly grazed in the lower-altitude area of the paddock, covering a wider area than at night. During the nighttime (Figure 4b), the cows spent most of their time in the higher-altitude area of the paddock, with less eating activity.

(a) Daytime (9:00 to 15:00)



(b) Nighttime (21:00 to 3:00)

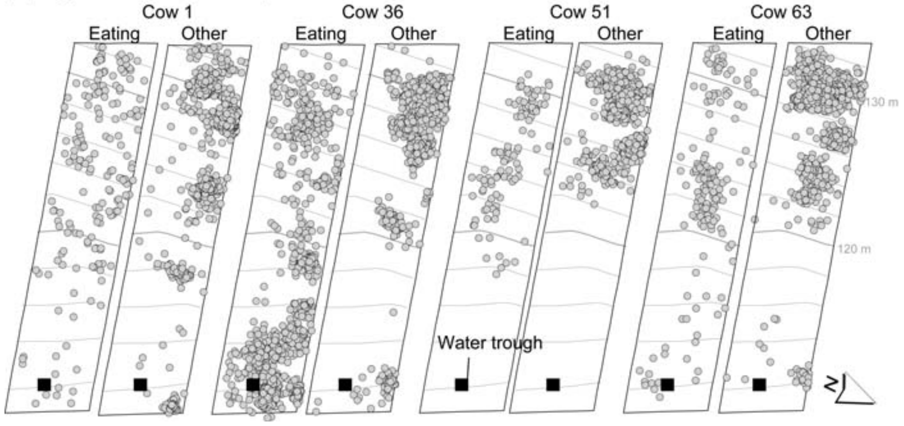


Figure 4. Spatial distributions of the cows' time spent eating and other activities during the (a) daytime (9:00 to 15:00) and (b) nighttime (21:00 to 3:00)

4. DISCUSSION

This study demonstrates that LCEX can be used to determine eating activity in grazing beef cows. The LCEX device was originally developed for research on human health and human health management (Kumahara et al. 2004; McClain et al. 2007) and was recently used by Ueda et al. (2011) for monitoring the eating activity of dairy cows. Ueda et al. showed that eating activity can be identified with less than 5.5% misclassification using AL_1 as a threshold value based on the 4-second data set, which corresponds to an activity level of 15 when simply calculated on a per-minute basis. Compared to this finding, our results based on the accumulated values of one-minute intervals indicated that results using the threshold values of 10.8 min^{-1} for LR and 8.9 min^{-1} for LDA obtained similar misclassification rates. Some previous studies have indicated that discriminant analysis is a useful method for identifying accelerometer variables that classify series of successive cow jaw movements into rumination and eating behaviors (Schleisner et al. 1999; Watanabe et al. 2008). In the present study, we found that LDA results showed a higher correct discrimination percentage for all cows (90.6 to 94.6%) than did the LR results (80.8 to 91.8%) (Figure 2).

The accelerometry-based activity monitor data using the LDA function was used to characterize the temporal organization of the cows' eating activities in the pasture and allowed calculation of the hourly and daily time the cows spent eating (Table 1 and Figure 3). The diurnal pattern of the cows observed in the present study confirmed previous reports that cows graze more during daylight hours than at night (Ueda et al. 2011). There were two major grazing periods during the day: a long afternoon period and a shorter morning period, which were in accordance with the result of Lin et al. 2011 and Schlecht et al. 2004). By combining the cow GPS locations and the spatial distributions of eating and other activities during the daytime and nighttime, we can conclude that the cows preferred to graze on the lower-altitude areas of the paddock during the day and, in contrast, spent most of in the night in the higher-altitude area with little eating activity (Figure 4). These results are in agreement with a previous study of bovine spatial distribution during grazing and resting in a hilly paddock (Watanabe et al. 2010).

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