

Spectral Analysis of Feeding and Lying Behavior of Cattle Kept Under Different Feedlot Conditions

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This study used spectral analysis in 2 separate experiments to examine feeding and lying behavior of *Bos taurus* steers under 2 housing treatments: a feedlot yard stocked at 12.0 m² per head with a dry, firm pen surface (NDF) and a “high density” (HDF) feedlot yard stocked at 6.0 m² per head with a wet and muddy feedlot pen surface. The study conducted 1 experiment in Autumn, another in Spring. The study measured and analyzed ambient temperatures, relative humidity, and barometric pressure half-hourly onsite, using time series cross-correlations to determine whether steer behavior was associated with them. Both NDF and HDF groups showed similar lying and eating duration. HDF steers exhibited patterns of lying and feeding different from those of NDF steers. Spring observations found a number of correlations with temperature, relative humidity, and barometric pressure. Health and production data showed no differences between treatments. The results indicate that cattle made successful, short-term changes to changed feedlot environmental conditions. However, confirming these findings requires further replication. Spectral analysis was shown to be sensitive enough to detect behavioral differences between treatments and thus has potential animal welfare assessment tool.

Studies of the patterns of lying and feeding behavior of cattle have provided information on issues such as dietary manipulations (Beauchemin, Kachanoski,

Schaalje, & Buchanan-Smith, 1990); health status (Sowell et al., 1999); and the evaluation of, and rates of adaptation to, new environments (Lidfors 1989; Veissier, Le Neindre, & Trillat, 1989). Examinations of changes and disruptions-to-rest patterns in cattle are of interest because cattle have a strong motivation for rest (Metz 1985; Ruckebusch 1972) and because disrupted sleep cycles have been related to stress and altered immune parameters in other species (Moldovsky, 1995; Toth, 1995). Resting time also has been studied as an indicator of cow comfort (Haley, Rushen, & de Passille, 2000). Therefore, the study of sleep patterns has value in animal welfare assessment. Similarly, bovine feeding rates and behavior have been used as an aid in assessing welfare status and in evaluating rates of adaptation to new environments (Fell et al., 1998; Howard, 2004). Feeding behavior has been observed to follow a circadian rhythm, associated with intake and digestion (Beauchemin et al., 1990; Champion, Rutter, Penning, & Rook, 1994; Deswysen, Dutilleul, Godfrin, & Ellis, 1993).

Spectral analysis can be used to examine the rhythms of resting and feeding and thus has potential as an animal welfare assessment tool. Spectral analysis enables a time series as a whole to be described in terms of the frequency of effects or events such as lying and feeding in time. It identifies cycle lengths that are responsible for large proportions of the variance in time-series data (Warner, 1998).

The aim of this study was to use spectral analysis to examine the patterns of lying and feeding behavior of cattle kept under two treatments (Standing Committee on Agriculture and Resource Management, 1997): (a) normal density feedlot (NDF) and (b) "high density" feedlot (HDF) with a wet substrate. Associations between temperature, relative humidity, and barometric pressure with feeding and lying behaviors also were investigated. This study was part of another that examined physiological changes between these treatments and a grazing treatment (Wilson, Fell, Colditz, & Collins, 2002).

METHOD

This study was performed at the New South Wales Agriculture Elizabeth Macarthur Agricultural Institute from April to May, 1996 (Experiment 1) and October to November, 1996 (Experiment 2). The Animal Care and Ethics Committee approved the study.

Experimental Treatments

Matched groups of *Bos taurus* steers received one of two treatments: (a) a feedlot yard with a stocking density of 12 m² per steer and a firm dry pen surface, featuring feed bunk space of 900 mm per head (NDF); and (b) a HDF yard with

a stocking density of 6 m² per steer, feed bunk space of 450 mm per head, and a wet and muddy pen surface. The surface of both pens was comprised of cattle manure hard packed to a depth of at least 15 cm over a gravel base. The wet pen surface was designed to interfere with lying behavior of the steers and to create more competition at the feeding trough. These conditions were designed to represent a poorly managed feedlot under prolonged wet conditions. The surface was wetted initially for the first 3 days. Then, the moisture from the cattle urine and fecal material kept the pad moist.

A total of 28 beef steers were used in Experiment 1 (14 steers per treatment group). The two groups were matched on the basis of age, breed, and weight. In Experiment 1 (Autumn), there were 10 Angus and 4 Angus × Hereford animals in each treatment. Steers were 20 months of age. Initial mean liveweights ($\pm SE$) were NDF: 381 \pm 6 kg; HDF: 384 \pm 7 kg. In Experiment 2 (Spring), 14 Angus steers of 21 months of age were used in each treatment. Mean liveweights ($\pm SE$) were NDF: 361 \pm 3 kg and HDF: 359 \pm 5 kg. The steers in each experiment had been raised together in a range environment. Before each experiment, all animals were screened for a range of bacterial and viral pathogens and found to be free of disease.

Feeding Regimen

Both feedlot groups were fed at 0800 hr and 1600 hr each day. At the start of the behavior observations, the ration was 20% chaff (lucerne, clover, and oats) and 80% of a commercial pelleted feed. Standard feed analysis revealed that the chaff was approximately 90% dry matter (DM) with 14% crude protein (CP) and 8.3 Megajoules (MJ) metabolizable energy (ME) per kg DM; the pellets were 89% DM with 21% CP and 12.5 MJ ME per kg DM. The amount fed was calculated as 3% of liveweight per day. Rejected feed was weighed and the amount offered at the subsequent feeding was adjusted to reduce the amount rejected.

Observations

Observations of both groups were conducted simultaneously in 4-hr blocks. The blocks were conducted as follows: 4 hr of observations, followed by a 4-hr break followed by 4 hr of observations. Scan samples with a scan interval of 10 min were conducted inside each 4-hr block. This technique was continued for 42 days to allow capture of steer behavior over all time periods. The 4-hr blocks then were combined over 48 hr to provide 24 hr of observations. Although the method was noncontinuous, the grouping of the 4-hr blocks over a 48-hr period and the grouping of the 48-hr blocks allowed for compensation for local disrup-

tions such as heavy rain or fog and power failures to the video recording equipment. To facilitate the observations, all cattle were monitored with an infrared, closed circuit TV system (GEC Panasonic, Sydney, New South Wales, Australia). Two video cameras per pen were used. Mounted on 5 m poles, they were situated at both ends of each pen. Cameras were linked to a time-lapse video recorder (Panasonic TL AG-6024, GEC Panasonic, Sydney, New South Wales, Australia).

Behavior

Steer activity was expressed as minutes feeding or lying per hour. Feeding was defined as the animal's having its head in the feedbunk or above the feedbunk—visibly chewing. Lying was defined as the animal's having adopted a recumbent position. Spectral analysis was used to investigate the cyclical nature of lying and feeding behavior. This analysis of time series relies on observations being in sequential order, having equal time increments, and being of the same duration with no missing values. In this case, 14 steers completed the study in both treatments at both times of the year, a total of 56 steers. Composite hourly observations for each steer were calculated from each 10-min observation period over the 42 days. The time spent grazing per hour for each steer was then calculated and the data combined into a 48-hr block.

Compared to standard descriptive procedures, spectral analysis is complex. Warner (1998), an excellent text, is recommended to the interested reader for a good description and introduction to the subject. Essentially, time series data is assessed (a) for the presence of a linear or nonlinear trend, which may account for a degree of variance in the series, and (b) for the presence of cycles or periodic components, which may account for the residual variance. If there is no trend, then the cycles may account for all the variance. Variation because of a linear trend can be determined with a simple linear regression equation using responses against observation numbers or time (t). Variance because of cyclic components is determined using a trigonometric function of t that represents a waveform plus parameters allowing for the determination of phase and amplitude of the period or cycle.

Specifically, spectral analysis considers partitioning the total variation in a time series into sums of squares that are contributed by different cyclical components. These cyclical components are identified by frequency and a total of $n/2$ frequencies are calculated where n is the number of observations in the time series. These are Fourier frequencies and equal $\omega = 2\pi/n$. For each Fourier frequency, an ordinate, or sum of squares, is calculated by the following equation:

$$I(\omega) = \left[\left\{ \sum_{t=1}^n y_t \cos(\omega t) \right\}^2 + \left\{ \sum_{t=1}^n y_t \sin(\omega t) \right\}^2 \right] / n,$$

where $I(\omega)$ is the ordinate due to each Fourier frequency (ω), n is the number of observations in the time series, and t represents time, in hours (Seman, Stuedemann, & Hill, 1999).

Ordinates were plotted against cycle length on a periodogram. Significantly large ordinates were identified by an F test, $F(2, 2m - 2)$, where m was the largest integer that was greater than or equal to $(n - 1)/2$. This tests whether the coefficients of the sine and cosine functions equal zero (no significant cycles) versus the alternative hypothesis that they are not equal to zero and there is a significant contribution of the sum of squares at this cycle length (Fuller, 1976). In other words, these cycles contribute significantly to the variance in the time series data and do not represent random variance or "white noise" in the data.

To determine if the feeding and resting cycles are different between the two treatments, the spectra of two measurements were compared using the procedure of Diggle (1990). That is, a composite ordinate for each treatment was computed by averaging the ordinates for all the steers in a treatment at each Fourier frequency. To compare periodogram averages, the ratio between the average ordinates was calculated with an F distribution of $2r_1, 2r_2, df$, where r_1 and r_2 are the number of steers in each treatment (14). When the ratio is graphed together with upper and lower F values, ratios exceeding the F critical boundaries indicate significant pointwise differences between the time series. To determine if two spectra are different, and thus if steers in two different treatments exhibited different feeding or lying behavior, Diggle outlined a test based on the maximum and minimum ratios.

To estimate how temperature, relative humidity, and barometric pressure influenced feeding and lying time, time series correlations were calculated from half-hourly ambient temperatures, relative humidity, and barometric pressure measured onsite during the measurement periods. The cross-correlation function (Box & Jenkins, 1976) was used to discover if two time series were related. Cross correlations were plotted by lags. Lags are in units of hours where the lag $t = 0$ (or the present time), at $t - 1$ hr is lag -1 , time $t - 2$ is lag -2 , and so forth. Negative lags related feeding and lying time to past meteorological measurements although positive lags related behavior to future meteorological measurements.

RESULTS

Cyclic Behavior

The average minutes per hour spent feeding and lying for the two treatments in Spring and Autumn are displayed in Table 1. These results show that NDF and HDF steers were similar with regard to time spent feeding or lying. However, Figures 1 and 2 show that there are different patterns of feeding and lying exhibited by cattle between the treatments.

TABLE 1
Summary of Behavior of Feedlot Steers Under Two Different Types of Management During 48-hr Periods in Autumn and Spring

<i>Time of Year</i>	<i>Activity</i>	<i>N</i>	<i>NDF</i> ^a	\pm <i>SE</i>	<i>HDF</i> ^a	\pm <i>SE</i>
Autumn	Feeding	14	126.9	36.9	124.1	15.1
	Lying	14	618.6	65.2	573.1	40.1
Spring	Lying	14	160.7	50.1	103.5	18.9
	Feeding	14	607.9	101.5	609.9	47.1

Note. NDF = normal feedlot; HDF = high density feedlot.

^aValues are *M* total minutes spent in each activity for 24 hrs of observation recorded in alternate 4-hr intervals over 48 hrs.

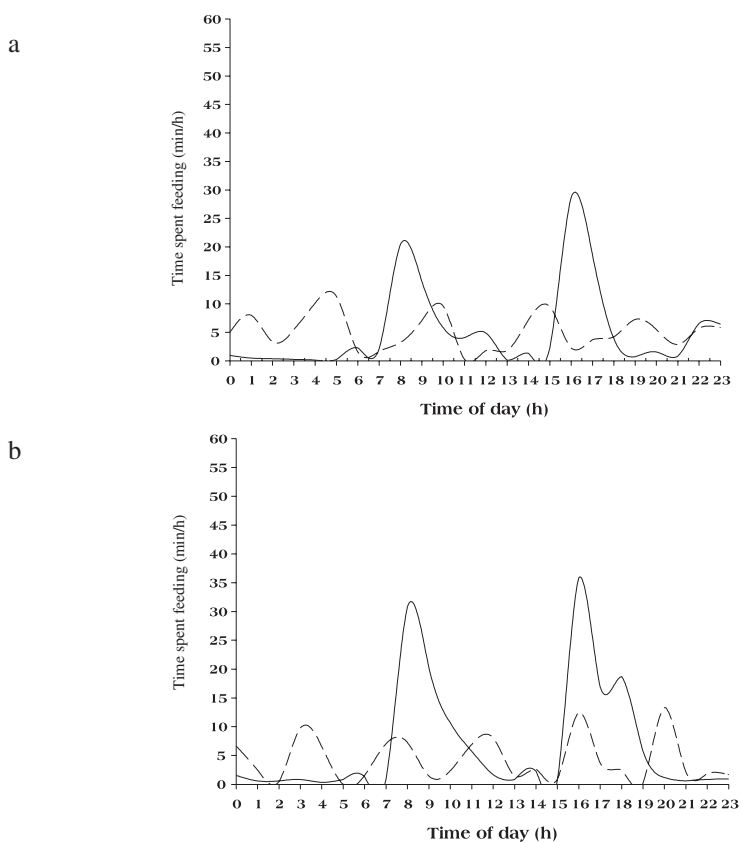


FIGURE 1 Mean circadian patterns of feeding for feedlot steers under two treatments: normal density feedlot (—) and high density feedlot (——) steers in (a) Autumn and (b) Spring.

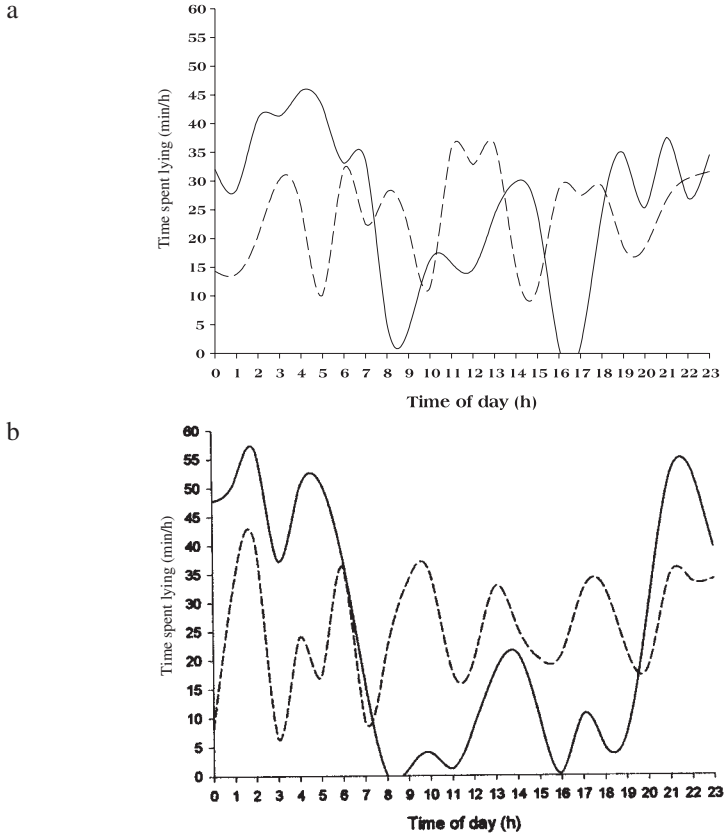


FIGURE 2 Mean circadian patterns of lying for feedlot steers under two treatments: normal density feedlot (____) and high density feedlot (----) steers in (a) Autumn and (b) Spring.

The average ordinates for both treatments at both times of the year are shown in Figures 3(a, b) and 4(a, b), respectively. Exceeding the F critical value identifies cycle lengths that significantly contribute to feeding or lying cyclicality. In Autumn (Figure 3a), NDF steers exhibited cycling feeding behavior occurring every 8 hr, while HDF steers exhibited cycling every 5 hr. In Spring (Figure 3b), NDF steers exhibited cycling feeding behavior occurring every 3 hr, while HDF steers exhibited cycling every 4 hr. Steers in the NDF treatments exhibited lying behavior every 8 hr for both times of the year, while those steers in the HDF treatment exhibited lying behavior every 5 and 4 hr for Autumn and Spring, respectively (Figure 4).

The ratio of ordinates and the 5% and 95% critical values were examined to determine if cyclicality differed between treatments. For feeding behavior, in Au-

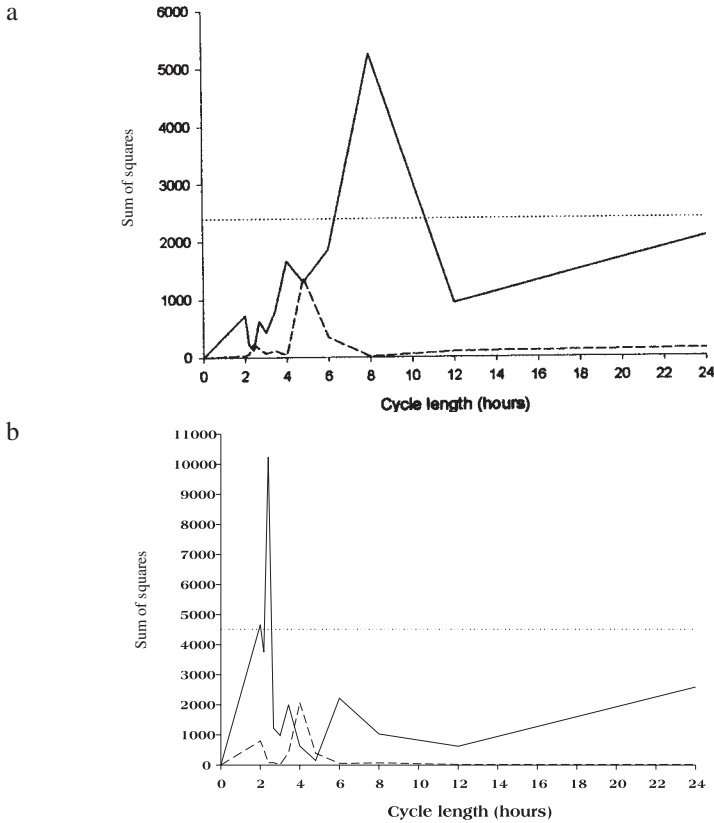


FIGURE 3 Periodogram plotting ordinates of feeding behavior due to each Fourier frequency cycle length for feedlot steers under two treatments: normal density feedlot (____) and high density feedlot (- - - -) steers in (a) Autumn and (b) Spring. (.....) approximate F ($p < .05$).

tumn, the ratio exceeded the critical value 9 times at cycles 2, 2.18, 3, 3.4, 4, 6, 8, 12, and 24 hr. In Spring, the ratio exceeded the critical value 6 times, at cycles 2.4, 4, 4.8, 8, 12, and 24 hr. For lying behavior, the ratio exceeded the critical value 9 times, at cycles 2, 2.4, 2.7, 3, 4.8, 6, 8, 12, and 24 hr. In Spring, the ratio exceeded the critical value 11 times at cycles 2, 2.18, 2.4, 2.7, 3, 3.4, 4, 6, 8, 12, and 24 hr.

Major differences between the NDF and HDF spectra at both times of the year occurred at the shorter cycle lengths. The maximum and minimum ratio statistical test verifies that the two spectra were different ($p < .05$) for each time of the year and that NDF and HDF steers behaved differently.

Environmental Influences

Temperature, relative humidity, and barometric pressure were not correlated ($p > .05$) with feeding behavior of either treatment group during the Autumn. However, temperature was correlated positively ($p < .05$) with feeding behavior of the NDF steers during the Spring. Relative humidity was correlated negatively ($p < .05$) with feeding behavior for the NDF steers during the Spring but this was restricted to the early times of the day (0100 to 0300 hr). There was no correlation ($p > .05$) between barometric pressure and feeding behavior with the NDF and HDF steers during Spring. Temperature and barometric pressure were

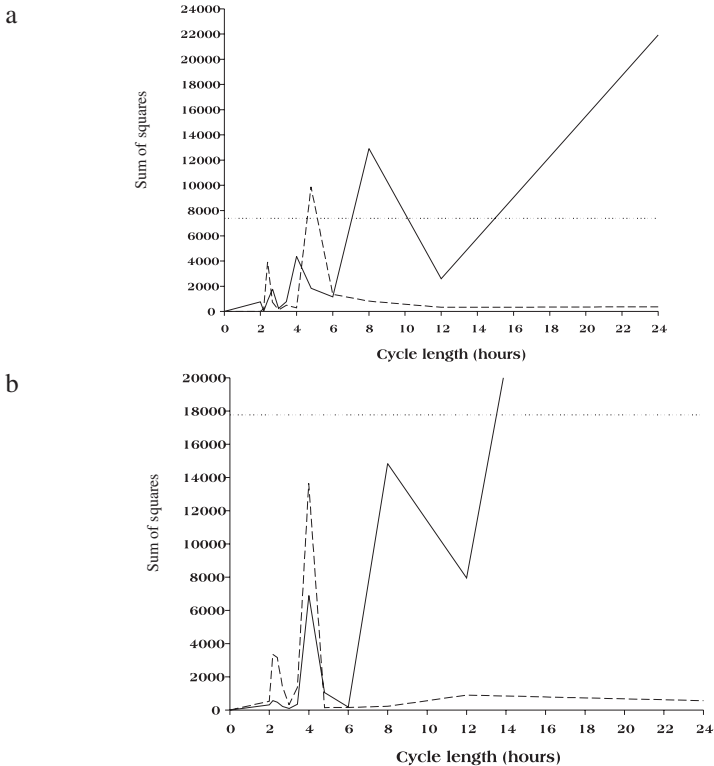


FIGURE 4 Periodogram plotting ordinates of lying behavior due to each Fourier frequency cycle length for feedlot steers under two treatments: normal density feedlot (—) and high density feedlot (----) steers in (a) Autumn and (b) Spring. (.....) approximate $F(p < .05)$.

correlated negatively and relative humidity was correlated positively with lying behavior for NDF but not HDF treatment steers.

Health and Production

There were no signs of clinical or subclinical disease in any animals and no disease-related lesions on any part of the carcasses were found at the abattoir. In Experiment 1, there was little difference in weight gain between the two treatments (HDF: 1.62 kg/day; NDF: 1.60 kg/day). The results were similar in Experiment 2 (HDF: 1.44 kg/day; NDF: 1.55 kg/day).

DISCUSSION

The duration of feeding and lying between the two groups was similar, despite the HDF steers being kept under different environmental conditions from those of the NDF steers. This similarity is attributed to the differences of patterns of lying and feeding exhibited by the HDF steers as shown by spectral analysis. However, the feedlot pen was the experimental unit, resulting in $N = 2$. Therefore, further studies would be required to confirm if these differences are consistent.

High cattle densities have been associated negatively with daily weight gain, feed conversion ratios, and dry matter intake (Ingvarlsen & Andersen, 1993). Lying time can also be affected (Morgensen, Nielsen, Hindhed, Sornsen, & Krohn, 1997) and this can have an energetic cost (Ortigue, Martin, Vermorel, & Anglaret, 1994). In our study, however, both groups were similar in terms of production parameters. Wilson et al. (2002) also found few physiological indicators that differed between treatments among the same animals.

It is possible that the HDF conditions were not severe enough to affect these parameters or that the 42 day duration of the study was not long enough for an effect to become apparent. Alternatively, the difference in pattern of feeding and lying between the HDF and NDF cattle enabled HDF cattle to cope relatively successfully with altered conditions. The behavioral changes may have been facilitated because cattle came from the same source and a stable social hierarchy was already well established (Bouissou, 1980; Johannesson & Sorensen, 2000; Stricklin, Graves, & Wilson, 1980).

Redbo, Ehrlemark, and Redbo-Torstensson (2001) found that dairy heifers altered their frequency of lying behavior in accordance with climactic changes. In our study, however, the correlations found between lying, feeding behavior and temperature, relative humidity, and barometric pressure did not follow a consistent pattern. In terms of seasonal changes, there were few differences in lying for both groups. However, the difference between seasons at the experimental site was not as extreme as it would have been in a Summer–Winter comparison.

SUMMARY

The results of this study indicate that spectral analysis can be a useful and sensitive tool for evaluating the effects of different environmental conditions on animal behavior. In conjunction with standard measures such as frequency and duration, a more comprehensive understanding of animal behavior can be obtained. This, in turn, can lead to a better assessment of the welfare status of animals who are under study.

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