An Automatic System for Quantification of Eating and Ruminating Activities of Dairy Cattle Housed in Stalls

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ABSTRACT

A system for quantifying eating and ruminating activities of dairy cows was developed and tested. A transducer was constructed using two strain gauges to transform cow jaw movements into electrical signals. The analog signals were processed into discrete jaw movements by a computerized data acquisition system. An interpretative program classified the input data into one of three categories: eating, ruminating, or idling. The accuracy of the system was tested using five cows for 5 d by comparing visual records to chart recorder and computer records. Estimates of time spent eating and ruminating produced by the computer and recorder during 24-h intervals were similar. However, recorder estimates of eating and ruminating were 17.6 and 4.7% longer than visual records, respectively, and computer estimates were 19.4 and 1.3% longer. Eating was overestimated by both automatic systems because the transducer was unable to distinguish between jaw movements caused by eating and grooming activities. In contrast, ruminating was estimated accurately by monitoring jaw movements.

INTRODUCTION

Intake of forages by ruminants is limited by rate of particle size reduction, enabling subsequent removal of undigested feed from the reticulorumen and passage through the digestive tract. Comminution of feedstuffs results principally from chewing during rumination and eating (16). Chewing during eating and rumination is also associated with increased saliva production (2, 12). Saliva buffers products of fermentation within the rumen, thereby maintaining optimal conditions for cellulolytic activity, which is crucial for the high producing dairy cow. Therefore, the ability to quantify eating and ruminating activities of cattle is desirable to provide greater understanding of the effects and significance of chewing on feed utilization and animal performance.

Eating and ruminating activities of sheep and cattle have been monitored by visual observation. However, this technique is laborious and precludes the use of a large number of animals for extended periods of observation. To overcome the difficulties of visual observation, various sensing devices have been used to detect jaw movement as an approach to measuring chewing. A pneumatic transducer, which measures fluctuations in air pressure resulting from jaw movements, has been used successfully (3, 5, 9, 14). Transducers that measure voltage changes occurring in proportion to jaw movement have also been used (4, 10). Penning (10) described the construction of a carbon-filled silicon tube into which two electrodes were inserted. Harumoto and Kato (4) used a strain gauge mounted on a leather halter.

The analog signal produced by these transducers has been monitored using a chart recorder (5) or cassette recorder (10); however, these systems require labor-intensive manual summarization of the data. In addition, these systems record chewing time, but do not characterize the behavior. A computer program that interprets such analog signals was developed by Penning et al. (11) for grazing sheep and by Leveillé et al. (6) for tethered sheep. Luginbuhl et al. (7) developed a computerized system to record a pulse signal produced by a transducer. However, data storage per animal for each 24-h period was slow; hence, data collection

Received July 6, 1988.
Accepted March 10, 1989.

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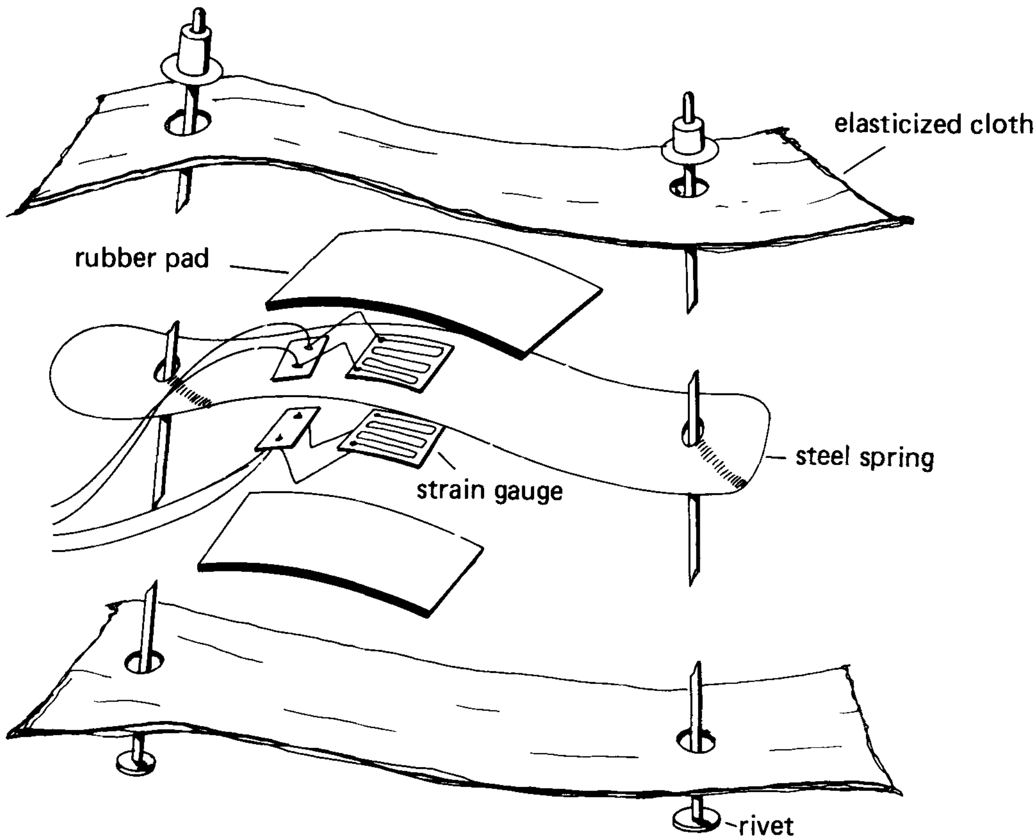

Figure 1. Strain-gauge transducer.

was prevented for lengthy periods during transfer to floppy disk. The objective of this research was to develop and implement a complete system to record automatically and to summarize daily eating and ruminating activities of dairy cattle housed in stalls. The relative accuracy of both the sensing device and the data acquisition system was evaluated.

MATERIALS AND METHODS

The complete system comprises transducers that monitor jaw movements and a computerized data acquisition system with capabilities of providing hourly and daily summaries of chewing activities for up to six cows.

Transducer

Each transducer was constructed to transform a cow's jaw movements into an electrical signal. A strip of spring steel (12 cm in length, 5 cm in width) was formed into a concave shape as shown in Figure 1. Two strain gauges (EA-06-125AD-120, Intertechnology Ltd., Toronto, Ont., Can.) were bonded to the steel, one to the top and a second to the bottom. The gauges were covered with a protective coating of M Bond 43B (Intertechnology Ltd., Toronto) and then by 2.0-mm thick rubber pads. The spring steel was riveted between two pieces of elasticized cloth and then attached to a leather halter as shown in Figure 2. Jaw movements caused the spring to flatten putting the top strain gauge in compression and the bottom one in tension. Consequently, the former decreased in resistance, and the latter increased.

Electrical connections were made to the strain gauge via a cable running under the cow's jaw perpendicular to the spring steel transducer. Initially the cable was positioned

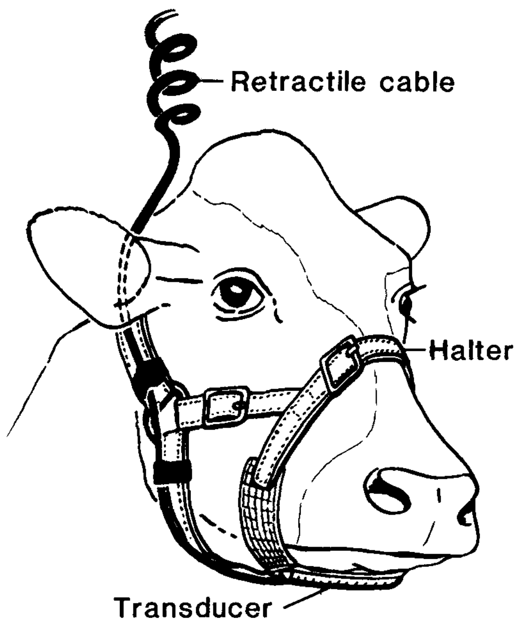

Figure 2. Transducer attached to leather halter.

along the top and bottom pieces of elasticized cloth. Despite careful stress-relieving measures, the large amount of flexing resulting from the cow's jaw movements caused frequent breakage of this cable. This problem was resolved by bringing the cable out perpendicular to the steel spring between two pieces of leather and threading it along the halter to the top of the cow's head. A retractile cable was connected from the halter to the ceiling, enabling the cow to move her head freely.

The strain gauges were electrically connected to form a simple voltage divider circuit (Figure 3). The voltage at point a was given by:

$$V_a = [R_b/(R_b + \Delta R_t)] \cdot V_s$$

where R_t = resistance of top strain gauge, R_b = resistance of bottom strain gauge, and V_s = fixed voltage supply. When $R_t = R_b = R$, then $V_a = V_s / 2$, where R is the unstressed strain gauge resistance. When the cow opened her mouth, R_t decreased to $R - \Delta R$ and R_b increased to $R + \Delta R$, and the voltage at point a was given by:

$$V_a = (R + \Delta R)/[(R - \Delta R) + (R + \Delta R)] \cdot V_s,\ V_a > V_s / 2.$$

When the cow closed her mouth, V_a returned to the value $V_s / 2$. Hence, V_a was a fluctuating signal with frequency and size of fluctuations depending on the cow's jaw movements.

This signal was amplified with an AC voltage amplifier having a variable gain of 50 to 100. This was used to amplify only the fluctuating portion of the voltage:

$$V_a = [\Delta R/2R \cdot V_s],$$

since it contained all the information about the jaw movement.

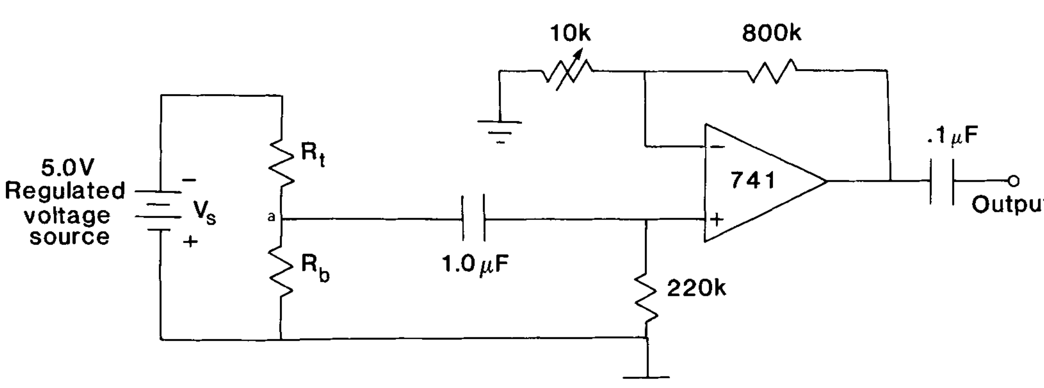

Figure 3. Voltage-divider circuit.

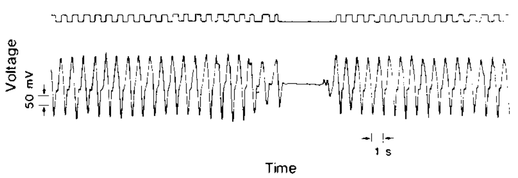

Figure 4. Chart recording analog input signal from the transducer during rumination (bottom) and corresponding computerized results (top).

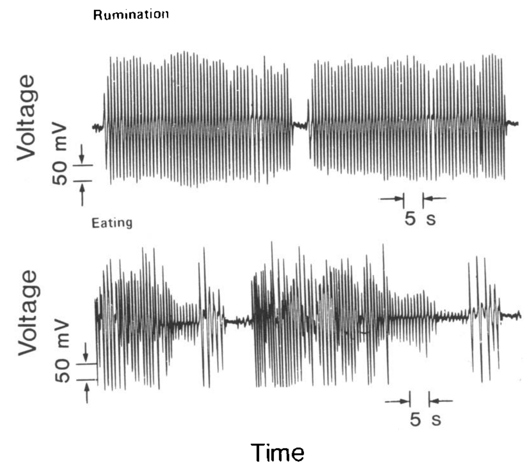

Figure 5. Typical analog signals produced during eating (bottom) and rumination (top).

Data Acquisition

The voltage signal was conveyed from the amplifier to the data acquisition system located approximately 50 m from where cows were housed. The analog signal was amplified tenfold and then digitized using a 12-bit analog to digital converter (PC Mate Lab Master, Techmar Inc., Ohio) installed in an IBM personal computer (with 320 kilobytes random access memory).

An algorithm programmed in BASIC was used to process the digitized signal into discrete chews. The signal from each cow was sampled at 25 Hz. A chew was registered when the difference between the minimum and maximum signal was greater than a predetermined magnitude, set by the user. This avoided problems associated with a drifting baseline and voltage fluctuations due to noise. The user could verify the recording accuracy by displaying the analog input signal and corresponding computerized results on a chart recorder (Figure 4).

Typical analog signals produced during eating and rumination are presented in Figure 5. Chewing during eating does not display a repetitive pattern; the rate of chewing varies with time, and pauses within a meal are erratic. In contrast, rumination is characterized by a series of boli separated by short pauses. The chewing speed during a bolus is relatively constant.

The chewing data for all six cows were retained in memory for up to 30 h then transferred to a floppy disk. It was necessary to halt collection during this transfer, but the entire process was completed in less than 2 min; hence, little information was lost. These chewing data were subsequently summarized using an interpretative program written in BASIC. This second program scanned the input data, which were composed of a string of integers representing the number of chews in each 2-s interval, and then classified the periods of activity and inactivity into one of three categories: idling, eating, and ruminating. The inactive periods were marked as: 1) rumination pauses if duration was less than 31 s and occurring during a rumination period, 2) eating pauses if duration was less than 2 min and occurring during a meal, or 3) idle periods otherwise. Very short active periods (less than 10 s) were considered part of the previous inactive period.

A scoring system was used to distinguish between active chewing during rumination periods and meals. Active periods were assigned a score indicating the likelihood that the chewing was part of a rumination period. Scores were based on the duration of chewing activity, the number and standard deviation of chews per second, and the duration of the preceding and succeeding pauses. Four consecutive periods of active chewing with high rumination scores constituted a rumination period. Each rumination period was then extended to include all boli, with slightly lower rumination scores that occurred before and after these four, until a period of nonrumination was encountered. Once included in a rumination period, each active period was denoted as a rumination bolus.

All other chewing occurred during meals. Eating periods and eating pauses were combined to form meals. Eating periods, separated by at least 4 min of inactivity, were considered

```
Data file:  B:09181241.6s
Start time:  12:41:14
Duration:  86400 s or 24 h

                                   Minutes

                1111111111222222222233333333334444444444555555555
Hour  012345678901234567890123456789012345678901234567890123456789

12:00 ----------------------------------------- EEEEEEEEEEEEEEEEEE
13:00 EEEEEEEEEEEEE           EEEEEEE       EEEEEEEEEEEEEEEEEEEEEE
14:00 E   EEEEEE                      RRRRRRRRRRRRRRRRRRRRRRRRRRRR
15:00 R             EEEEEEEEEEEEEEEEE                         RRRR
16:00 RRRRRRRRRRRRRRRRR
17:00                                              RRRRR RRRRRRRRR
18:00 RRRRRRRRRRRRRRR
19:00                    RRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRR
20:00                  RRRRRRRRRRRRRRRRRRRRRRRRRRRRR
21:00                      RRRRRRRRRRRRRRRRRRRRRRRRRRRR
22:00
23:00                             RRRRRRRRRRRRRRRRRRRRRRRRRRRRRR
 0:00                                             RRRRRRRRRRRRRRRR
 1:00 RRRRRRRRRRRRRRRRRRRRRR
 2:00                                        RRRRRRRRRRRRRRRRRRRRR
 3:00 RRRRRRRRRRRRRRRRRRRRRRRRRRRR
 4:00            RRRRRRRRRRRRRRRRRRRRRRR
 5:00                   EEEEEEEEEEEEEEEEEEEE
 6:00              EEEEEEEEEEEEEEEEEE
 7:00              EEEEEEEEEEEEEEEEEE
 8:00           EEEEEE            EEEEEEEEEEEEE  RRRRRRRRRRRRRRRRR
 9:00                        RRRRRRRRRRRRRRRRRRRRRRRRRRRR
10:00                         RRRRRRRRRRRRRRRRRRRRRRRRRRRRR
11:00                                                         RRRR
12:00  RRRRRRRRRRRRR RRRRRRRRRRRRRRR           -------------------
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Figure 6. Daily summary of chewing activities.

to be two different meals. Meals of less than 2 min, or less than 4 min if the chewing rate was slower than 1 chew/s, were considered to be idle periods. Chewing that followed eating by less than 30 s was denoted as eating.

The interpretative program summarized daily chewing activities for each cow by time, chews, meals, and rumination periods. An example of each of the tables produced are provided in Figure 6 and Tables 1, 2, 3, and 4. Figure 6 offers an overview of the daily eating and rumination periods enabling rapid detection of anomalies or equipment malfunction. Hours are listed vertically and minutes are listed horizontally. The letter E indicates eating, R denotes rumination, and the absence of a letter signifies an idle period. Table 1 provides a listing of minutes attributed to each chewing activity by hour and day. Similarly, Table 2 lists the number of chews occurring as a result of each activity on an hourly and daily basis. A summary of each meal is given in Table 3, and rumination periods are described in Table 4. The interpretative program also simultaneously

TABLE 1. Time spent eating, ruminating, chewing, and idling summarized hourly and daily. File: B:09181241.6s

Hours	Idle		Eating		Ruminating		Chewing		Total	
	(min)	(%)	(min)	(%)	(min)	(%)	(min)	(%)	(min)	(%)
1241	1.1	6.0	17.7	94.0	0	0	17.7	94.0	18.8	100.0
1300	18.5	30.8	41.5	69.2	0	0	41.5	69.2	60.0	100.0
1400	24.7	41.1	7.6	12.6	27.8	46.3	35.3	58.9	60.0	100.0
1500	37.7	62.8	17.7	29.4	4.7	7.8	22.3	37.2	60.0	100.0
1600	42.7	71.2	0	0	17.3	28.8	17.3	28.8	60.0	100.0
1700	45.1	75.2	0	0	14.9	24.8	14.9	24.8	60.0	100.0
1800	44.5	74.2	0	0	15.5	25.8	15.5	25.8	60.0	100.0
1900	22.2	37.0	0	0	37.8	63.0	37.8	63.0	60.0	100.0
2000	31.9	53.1	0	0	28.1	46.9	28.1	46.9	60.0	100.0
2100	32.1	53.4	0	0	27.9	46.6	27.9	46.6	60.0	100.0
2200	60.0	100.0	0	0	0	0	0	0	60.0	100.0
2300	30.0	50.1	0	0	30.0	49.9	30.0	49.9	60.0	100.0
000	43.6	72.6	0	0	16.4	27.4	16.4	27.4	60.0	100.0
100	37.6	62.7	0	0	22.4	37.3	22.4	37.3	60.0	100.0
200	39.4	65.6	0	0	20.6	34.4	20.6	34.4	60.0	100.0
300	31.7	52.9	0	0	28.3	47.1	28.3	47.1	60.0	100.0
400	36.8	61.4	0	0	23.2	38.6	23.2	38.6	60.0	100.0
500	39.8	66.3	20.2	33.7	0	0	20.2	33.7	60.0	100.0
600	43.1	71.8	16.9	28.2	0	0	16.9	28.2	60.0	100.0
700	42.0	10.0	18.0	30.0	0	0	18.0	30.0	60.0	100.0
800	24.4	40.7	19.2	31.9	16.4	27.4	35.6	59.3	60.0	100.0
900	31.3	52.1	0	0	28.7	47.9	28.7	47.9	60.0	100.0
1000	30.9	51.5	0	0	29.1	48.5	29.1	48.5	60.0	100.0
1100	56.8	94.7	0	0	3.2	5.3	3.2	5.3	60.0	100.0
1200	12.5	30.4	0	0	28.7	69.6	28.7	69.6	41.2	100.0
Day	860.3	59.7	158.7	11.0	421.0	29.2	579.7	40.3	1440.0	100.0

TABLE 2. Chews occurring during eating, ruminating, chewing, and idling summarized hourly and daily. File: B:09181241.6s

Hours	Idle		Eating		Ruminating		Chewing		Total	
	(no.)	(%)	(no.)	(%)	(no.)	(%)	(no.)	(%)	(no.)	(%)
1241	3	.2	1329	99.8	0	0	1329	99.8	1332	100.0
1300	39	1.5	2572	98.5	0	0	2572	98.5	2611	100.0
1400	232	10.4	317	14.3	1672	75.3	1989	89.6	2221	100.0
1500	73	4.2	1379	79.6	281	16.2	1660	95.8	1733	100.0
1600	73	6.6	0	6.0	1035	93.4	1035	93.4	1108	100.0
1700	21	2.4	0	0	863	97.6	863	97.6	884	100.0
1800	95	9.2	0	0	935	90.8	935	90.8	1030	100.0
1900	25	1.1	0	0	2259	98.9	2259	98.9	2284	100.0
2000	6	.4	0	0	1660	99.6	1660	99.6	1666	100.0
2100	68	3.9	0	0	1662	96.1	1662	96.1	1730	100.0
2200	219	100.0	0	0	0	0	0	0	219	100.0
2300	8	.4	0	0	1774	99.6	1774	99.6	1782	100.0
000	10	1.0	0	0	974	99.0	974	99.0	984	100.0
100	17	1.2	0	0	1347	98.8	1347	98.8	1364	100.0
200	65	5.1	0	0	1208	94.9	1208	94.9	1273	100.0
300	2	.1	0	0	1693	99.9	1693	99.9	1695	100.0
400	12	.9	0	0	1328	99.1	1328	99.1	1340	100.0
500	76	5.6	1270	94.4	0	0	1270	94.4	1346	100.0
600	502	30.3	1156	69.7	0	0	1156	69.7	1658	100.0
700	229	14.8	1316	85.2	0	0	1316	85.2	1545	100.0
800	79	3.8	999	48.0	1002	48.2	2001	96.2	2080	100.0
900	89	5.2	0	0	1607	94.8	1607	94.8	1696	100.0
1000	101	5.8	0	0	1646	94.2	1646	94.2	1747	100.0
1100	37	17.6	0	0	173	82.4	173	82.4	210	100.0
1200	44	2.7	0	0	1604	97.3	1604	97.3	1648	100.0
Day	2125	5.7	10,338	27.8	24,723	66.5	35,061	94.3	37,186	100.0

TABLE 3. Daily eating behavior summarized by meal. File: B:09181241.6s

Mean	Start time	Stop time	Duration	Total	Chews/min
			(min)		
1	1242	1313	31.2	2092	67.12
2	1324	1331	6.2	406	65.13
3	1338	1401	23.1	1452	62.86
4	1404	1410	6.2	268	42.99
5	1514	1531	17.7	1379	78.06
6	518	538	20.2	1270	62.77
7	612	629	16.9	1156	68.27
8	713	731	18.0	1316	73.11
9	809	815	6.0	266	44.58
10	828	841	13.2	733	55.53
Total	. . .	. . .	158.7	10,338	. . .
Mean	. . .	. . .	15.9	1034	65.13

creates an ASCII file in which the information from these tables is stored for further statistical or time series analysis. A file editing program was developed to join and shorten data files so that all files contained records for exactly 24 h.

Validation Trial

Five lactating Holstein cows were used to determine the accuracy of transducer measurement of jaw movements compared with records of visual observations for monitoring eating and ruminating behavior of stall-housed dairy cattle. In addition, computer summaries of the transducer signals were compared with manual interpretations of tracings produced by a chart recorder in order to evaluate the accuracy of the data acquisition system.

The trial was conducted over a 10-d period, including a 5-d period used to adapt the cows to wearing halters. During the experimental period, chewing activities of each cow were recorded continuously by the computer and recorder. Visual records of chewing activities were made by two trained observers during a 7-h span on each of the 5 d. The activity of each cow was recorded each minute, as either eating, ruminating, or idle. Eating was defined as prehension and mastication of feed. Licking and grooming activities were considered to be part of the idle category.

Cows were fed twice daily a silage-based complete diet formulated to supply NRC (8) requirements. Water was available at all times. Cows were milked in their stalls twice daily. The number of minutes each cow spent eating, ruminating, and chewing (total of eating and rumination) during the daily observation periods was determined from records of visual observations, summaries of chart recordings, and computer summaries. Similarly, chewing activities during the 24-h periods were summarized from chart recordings and by computer.

The relative accuracy of the chewing monitoring system was determined using statistical methodology described by Allen and Raktoe (1). The root mean squared error, given by:

$$\text{RMSE} = [1/n \sum_{i=1}^{n} (P_i - A_i)^2]^{1/2}$$

where RMSE = root mean squared error, n = number of observations, P = minutes spent eating, ruminating, or chewing using procedure 1 for either 7 or 24 h, and A = minutes spent eating, ruminating or chewing using procedure 2 for either 7 or 24 h, was used as a measure of the relative accuracy between two procedures for monitoring chewing behavior. Information concerning the sources of error was obtained by decomposing the mean squared error into three components of error, given by:

$$1/n \sum_{i=1}^{n} (P_i - A_i)^2 = (\bar{P} - \bar{A})^2 + (S_p - r \cdot S_a)^2 + (1 - r^2) \cdot S_a^2$$

TABLE 4. Dairy rumination behavior summarized by period. File: B:09181241.6s

Period	Start time	Stop time	Duration	Total chews	Chews/min	Boli No.	Boli Chews	Boli Duration	Boli Pause
	(h)	(h)	(min)				(s)	(s)	(s)
1	1432	1501	29.4	1780	60.61	37	48.00	43.19	4.43
2	1556	1617	20.4	1208	59.31	27	44.67	40.67	4.59
3	1744	1749	5.1	282	55.66	7	40.29	40.00	3.43
4	1750	1815	25.3	1516	59.84	30	50.33	46.00	4.67
5	1919	1957	37.8	2259	59.76	44	51.09	46.00	5.55
6	2017	2046	28.1	1660	59.00	31	53.52	50.58	3.87
7	2121	21.49	27.9	1662	59.50	32	51.91	47.69	4.69
8	2328	2358	30.0	1774	59.20	35	50.69	46.86	4.51
9	0043	0122	38.8	2321	59.77	40	58.03	54.25	4.00
10	0239	0328	48.9	2901	59.33	57	50.89	47.65	3.82
11	0411	0434	23.2	1328	57.32	25	52.88	51.36	4.24
12	0843	0900	17.1	1045	61.11	21	49.76	44.95	3.90
13	0922	0950	28.1	1564	55.72	33	47.30	45.03	6.00
14	1023	1052	29.1	1646	56.56	36	45.64	43.06	5.44
15	1156	1213	16.7	932	55.70	21	44.10	43.33	4.48
16	1214	1229	15.1	845	55.84	19	44.47	42.74	5.05
Total	...	...	421.0	24,723	...	495	...	...	...
Mean	...	...	26.3	1545	58.72	31	48.97	45.83	4.54

where:

$$\bar{P} = 1/n \sum_{i=1}^{n} P_i$$

$$\bar{A} = 1/n \sum_{i=1}^{n} A_i$$

$$S_p^2 = 1/n \sum_{i=1}^{n} (P_i - \bar{P})^2 ,$$

$$S_a^2 = 1/n \sum_{i=1}^{n} (A_i - \bar{A})^2 , \text{ and}$$

r = correlation coefficient.

The square root of the first component, i.e., $(\bar{P} - \bar{A})$, measures the mean bias between the two techniques, indicating the amount that P consistently underestimates or overestimates time spent chewing when compared to A. The square root of the second term, i.e., $(S_p - r \cdot S_a)$ is the error due to regression and is zero when the regression of A on P is unity. Slopes were calculated and tested for unity as follows (13):

$$S_{pa} = [\sum_{i=1}^{n} (P_i - \bar{P}) \cdot (A_i - \bar{A})]/n$$

and:

$$S_b^2 = S_a^2 - b2 \cdot S_p^2/[(n - 2) \cdot S_p^2$$

A slope of less than one would mean that for small values of P, A would tend to be larger than P, but for larger values of P, A would tend to be less than P. The square root of the third component, i.e., $[(1 - r^2) S_a^2]^{1/2}$ is a measure of random disturbance.

The mean differences between visual observation, chart recorder tracings, and computer summaries for monitoring chewing activities were determined using paired *t* tests (13). The effect of cow and day on the mean bias between these techniques was determined by analysis of variance on the mean bias between monitoring systems.

RESULTS AND DISCUSSION

The mean time that cows spent eating, ruminating, and chewing during the experiment is summarized in Table 5 according to the monitoring system used. Cows ate for approximately 222 min/d (SE 8) and ruminated 396 min/d (SE 18), resulting in a total of 618 min/d (SE 19) of chewing. The 7-h period contained 46% of the daily eating activity and was expected because the presentation of food, which initiates eating, occurred during this period. In contrast, only 19.5% of the rumination activity occurred during the observation period, which is consistent with observations that animals fed twice daily ruminate mainly during the early hours of the morning (15).

The relative accuracy of visual observation, chart recorder tracings, and computer summaries is presented in Table 6. The correlation between visual observation and both recording devices for measuring eating time was relatively low, ranging from .71 for the chart recorder and .67 for the computer. The difference

TABLE 5. Time spent eating, ruminating, and chewing by lactating dairy cows determined by visual observation, chart recorder, and computer (min).

Monitoring system	Eating		Rumination		Total chewing	
	$\bar{X}$	SE	$\bar{X}$	SE	$\bar{X}$	SE
24-h Period[1]						
Computer	225	8.7	393	19.0	617	19.0
Chart recorder	220	8.3	400	16.8	620	18.8
7-h Period[2]						
Visual	87	4.6	76	5.1	163	7.9
Computer	104	6.6	75	6.1	179	9.0
Chart recorder	102	6.1	80	5.2	182	9.0

[1]Mean of 20 observations.

[2]Mean of 25 observations.

TABLE 6. Relative accuracy of visual observations (VO), chart recorder tracings (CR), and computer summaries (CP) for monitoring chewing activities during a 7-h period.

Comparison	Eating	Rumination	Total chewing
CR-VO			
Root mean squared error, min	26.5	5.9	28.5
Mean bias between procedures			
min	15.3**	3.6**	18.9**
SE	2.9	.9	2.7
Error due to regression, min	14.3	.9	10.0
Slope	.75**	.98NS,1	.88**
Error due to random disturbance, min	16.2	4.6	18.8
Correlation coefficient	.71	.98	.88
CP-VO			
Root mean squared error, min	29.7	13.1	25.1
Mean bias between procedures			
min	16.9**	−1.2NS	15.7**
SE	3.5	2.6	2.8
Error due to regression, min	17.6	7.5	9.2
Slope	.69**	.83**	.88**
Error due to random disturbance, min	16.9	10.6	17.3
Correlation coefficient	.67	.91	.90
CP-CR			
Root mean squared error, min	13.6	13.4	6.1
Mean bias between procedures			
min	1.5	−4.8NS	−3.2**
SE	2.8	2.6	1.0
Error due to regression, min	5.2	6.8	.3
Slope	.92*	.85*	1.0NS
Error due to random disturbance, min	12.4	10.5	5.2
Correlation coefficient	.91	.91	.99

[1]Nonsignificant at $P>.05$.

*$P<.05$.

**$P<.01$.

between procedures was estimated using the root mean squared error, because the mean difference did not account for the cancelling effect of positive and negative differences. Visual records of eating differed from chart records by about 26.5 min per 7-h on average. Part of this difference can be attributed to the fact that mean eating time measured visually was 15.3 min less ($P<.01$) during a 7-h period than mean time measured by chart recorder. A difference of similar magnitude was observed between visual and computer summaries (i.e., root mean squared error = 29.7 min, mean difference 16.9 min).

The large discrepancy between estimating eating time visually and automatically can be attributed to the fact that only jaw movements occurring during prehension and mastication of food, and not those due to licking and grooming, were included in the eating category during visual observation. In contrast, discrimination of this type in chart and computer summaries was incomplete. Consequently, eating time was consistently overestimated when either automated recording system was used. The inability to distinguish between eating and grooming jaw movements must be recognized as a limitation of this system and all systems that monitor jaw movements as an indirect approach to measuring eating time. The accuracy of the present system for monitoring eating time could be improved upon in future experiments by simultaneously using digital scales linked to the data acquisition system. Scales would provide infor-

TABLE 7. Relative accuracy of computer (CP) and chart recorder (CR) for monitoring chewing activities of dairy cows during a 24-h period.

CP-CR	Eating	Rumination	Total chewing
Root mean squared error, min	15.0	16.7	11.4
Mean bias between procedures			
min	5.2	−7.6	−2.5
SE	2.3*	1.8**	1.4[NS,1]
Error due to regression min	4.3	10.4	1.6
Slope	.89**	.88**	.98**
Error due to random disturbance, min	13.4	10.6	11.0
Correlation coefficient	.93	.99	.99

[1]Nonsignificant at *P*>.05.

**P*<.05.

***P*<.01.

mation regarding feed intake each minute that could be used by the experimenter to distinguish between types of eating activity.

In contrast to eating, a high correlation (r = .91 to .98) existed between automatically recorded and visual observations for measuring rumination during the 7-h period. The root mean squared error indicated that the actual difference between computer summaries and visual observations (13.1 min) was greater than for chart records (5.9 min), possibly because at least four boli were needed by the computer program in order to detect rumination periods. In addition, on two occasions during the 5-d period, one cow ruminated intermittently, producing a highly irregular analog output. These periods were not denoted as rumination periods by the computer since the pattern of chewing did not conform to the necessary criteria. The mean difference between chart recordings and visual observation during the 7-h interval was 3.6 min (*P*<.05). A −1.2 min (*P*>.05) difference was obtained between computer and visual summaries.

TABLE 8. Effect of cow and day on the mean bias of monitoring activities using observation (VO), chart recorder tracings (CR), and computer summaries (CP).

Chewing activity	Procedures	Observation period	Level of significance	
			Cow	Period
		(h)		
Eating	CR vs. VO	7	NS[1]	NS
	CP vs. VO	7	NS	NS
	CP vs. CR	7	NS	NS
	CP vs. CR	24	**	NS
Rumination	CR vs. VO	7	**	NS
	CP vs. VO	7	**	NS
	CP vs. CR	7	NS	NS
	CP vs. CR	24	*	NS

[1]Nonsignificant at *P*>.05.

**P*<.05.

***P*<.01.

The root mean squared error when comparing the computer to that of the recorder during the 24-h recording period was 15.0 and 16.7 min for eating and rumination, respectively (Table 7). This represented 6.7% of average eating time and 4.2% of average ruminating time daily. The computer consistently overestimated ($P<.05$) eating by an average of 5.2 min/d and underestimated ($P<.01$) rumination by 7.6 min/d when compared to the chart recorder. Although a large proportion of the difference between the two recording procedures is random error, discrepancies in eating times were also due to small differences between estimates of termination of meals. Short rumination periods (less than 4 min) are not detected by the computer program and may account for some of the differences between procedures in measuring time spent ruminating.

The effect of cow and day on the mean bias between chewing monitoring systems is presented in Table 8. Differences between systems were not affected ($P>.05$) by day. However relative accuracy differed ($P<.05$) with respect to cow monitored, particularly for rumination. This suggests that selection of cows best suited to automatic monitoring prior to experimentation would further improve accuracy of measurements in relation to visual observations. However, this advantage must be weighed against the possible introduction of an element of bias in the experiment due to preselection of cows.

CONCLUSIONS

The system provides a complete approach to quantifying chewing activities in dairy cattle. Results from the validation trial suggest that this system and any system that monitors jaw movements as an indirect approach to measuring chewing overestimate eating time due to the inability to distinguish between jaw movements occurring during eating and grooming activities. In contrast, rumination can be monitored using a transducer with a high degree of accuracy. Computerization of data acquisition and summarization compared favorably to manual processing of chart recorder tracings for estimating both eating and rumination.

The unique features of the present system include: user friendliness, reliability over long periods, accuracy, and flexibility. Since its development, this chewing system has been used effectively as a research tool to study effect of diet on chewing in dairy cows and beef steers. Problems incurred have been minor and more than 500 daily chewing patterns have been recorded successfully.

ACKNOWLEDGMENTS

The authors wish to acknowledge Lloyd Swackhammer for his technical assistance in the construction of the transducers. The authors also appreciate the help of Cheryl Campbell for assisting with recording chewing behavior of cows and O. B. Allen for reviewing this manuscript. Financial assistance was provided by the Ontario Ministry of Agriculture and Food and the Natural Science and Engineering Research Council of Canada.

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