THE UNIVERSITY *of* EDINBURGH

Edinburgh Research Explorer

Comparison of rumination activity measured using rumination collars against direct visual observations and analysis of video recordings of dairy cows in commercial farm environments

Citation for published version:
Ambriz-Vilchis, V, Jessop, NS, Fawcett, RH, Shaw, DJ & Macrae, AI 2015, 'Comparison of rumination activity measured using rumination collars against direct visual observations and analysis of video recordings of dairy cows in commercial farm environments' Journal of Dairy Science, vol. 98, no. 3, pp. 1750-1758. DOI: 10.3168/jds.2014-8565

Digital Object Identifier (DOI):
10.3168/jds.2014-8565

Link:
Link to publication record in Edinburgh Research Explorer

Document Version:
Peer reviewed version

Published In:
Journal of Dairy Science

Comparison of rumination activity measured using rumination collars against direct visual observations and analysis of video recordings of dairy cows in commercial farm environments

Ambriz-Vilchis

INTERPRETATIVE SUMMARY

Automated systems for monitoring the behavior of cows have become increasingly important for management routines. Rumination has significant impacts on performance, health and welfare. In order to investigate rumination, accurate methods to measure rumination are essential. Our aim was to compare rumination activity measured with a rumination collar against that obtained by direct visual observations and analysis of video recordings in dairy cows. Our results suggest that the rumination collars can determine rumination activity and are a good alternative to visual observations when animals are housed indoors. However, they are not an alternative to direct observations with grazing animals.

Comparison of rumination activity measured using rumination collars against direct visual observations and analysis of video recordings of dairy cows in commercial farm environments

V. Ambriz-Vilchis*†[1], N. S. Jessop†, R.H. Fawcett†, D. J. Shaw‡ and A. I. Macrae*

*Dairy Herd Health and Productivity Service, Royal (Dick) School of Veterinary Studies and the Roslin Institute, The University of Edinburgh, Easter Bush Veterinary Centre, Roslin, Midlothian, EH25 9RG, Scotland, UK

†Bioparametrics Ltd. The Cottage SRUC Building, West Mains Road, Edinburgh, Lothian, EH9 3JG, Scotland, UK

‡Royal (Dick) School of Veterinary Studies and the Roslin Institute, The University of Edinburgh, Easter Bush Veterinary Centre, Roslin, Midlothian, EH25 9RG, Scotland, UK

[1]Virgilio Ambriz-Vilchis

Dairy Herd Health and Productivity Service, Royal (Dick) School of Veterinary Studies and the Roslin Institute, The University of Edinburgh, Easter Bush Veterinary Centre, Roslin, Midlothian, EH25 9RG, Scotland, UK.

Phone:+4401316517474

Fax:+4401316517473

V.Ambriz-Vilchis@sms.ed.ac.uk

ABSTRACT

Automated systems for monitoring the behavior of cows have become increasingly important for management routines and for monitoring health and welfare. In the past few decades various devices that record rumination have been developed. The aim of the present study was to compare rumination activity measured with a commercially available rumination collar (RC) against that obtained by direct visual observations and analysis of video recordings in commercial dairy cows. Rumination time from video recordings was recorded by a trained observer. To assess observer reliability, data was recorded twice, and the duration of recorded behaviors was very similar and highly correlated between these two measurements (mean = 39 ± 4 and 38 ± 4 min / 2 h). Measurements of rumination time obtained with RC when compared with analysis of video recordings and direct observations were variable: RC output was significantly positively related to observed rumination activity when dealing with housed animals indoors (Trial 1 video recordings: slope = 1.02, 95 % CI = 0.92 – 1.12), and the limits of agreement method (LoA) showed differences (in min per 2 hour block) to be within - 26.92 lower and 24.27 upper limits. Trial 1 direct observations: slope = 1.08, 95 % CI = 0.62 – 1.55, and the LoA showed differences to be within – 28.54 lower and 21.98 upper limits. Trial 2: slope = 0.93, 95 % CI = 0.64 – 1.23, and the LoA showed differences to be within – 32.56 lower and 19.84 upper limits). However the results were poor when cows were outside grazing grass (Trial 3: slope = 0.57, 95 % CI = 0.13 – 1.02, and the LoA showed differences to be within wider limits – 51.16 lower and 53.02 upper). Our results suggest that RC can determine rumination activity and are an alternative to visual observations when animals are housed indoors. However they are not an alternative to direct observations with grazing animals on pasture and its use is not advisable until further research and validation are carried out.

Key Words: dairy cow, rumination activity, validation, video recording, direct observation.

INTRODUCTION

Ruminants occupy an advantageous niche in the animal kingdom. Due to their digestive adaptations ruminants are capable of converting fibrous, cellulose-rich plant material to energy sources (Van Wieren S.E., 1996). These fibrous materials are firstly subject to pre-gastric fermentation, secondly regurgitated at frequent intervals, re-chewed and finally swallowed back for further degradation.

Rumination reduces the particle size of feedstuffs for rumen degradation, and initiates the process of extracting soluble contents from the feed (Van Soest, 1994). Furthermore, by stimulating saliva production, rumination aids in maintaining correct rumen function by keeping rumen pH within a suitable range for microbial cellulolytic activity (Beauchemin et al., 1989). A combination of factors influence rumination including: nutritional factors, the physical and chemical characteristics of the food material, environmental stressors and day length. For example, rations with fibrous feeds increase chewing activity, while high concentrate rations reduce rumination, which could lead to rumen acidosis.

Rumination has a significant impact on intake and forage utilization, which directly correlates to performance, health and welfare. Therefore it has been proposed that rumination activity could be used as an indicator of animal health and welfare (Weary et al., 2009). Changes in rumination time may be used as a proxy measure of illness or changes in health status, i.e. if detected, subtle changes in rumination activity could help in the detection of subclinical diseases before they progress and become a clinically apparent concern. To further investigate this possibility, accurate and precise methods to measure rumination time are required.

Visual observation is the standard and more reliable method to measure rumination. This can be done either through direct observations or by analysis of video recordings, however it presents some disadvantages, e.g., requires trained personnel and the number of animals that can be observed at a time is limited. Analysis of video recordings, on the other hand, allows observation of groups of animals and can be performed outwith the study site. Video observation also has limitations as it requires trained personal and relies on expensive infrastructure.

To overcome the difficulties posed by monitoring and recording behavior, automated equipment to record feeding behavior (eating and/or ruminating) have been developed. These devices can measure rumination by means of analyzing jaw movements (Beauchemin et al., 1989; Rutter et al., 1997; Kononoff et al., 2002; Umemura et al., 2009; Braun et al., 2013) or recording sounds of mastication (Laca and WallisDeVries, 2000; Schirmann et al., 2009; Clapham et al., 2011; Elischer et al., 2013; Goldhawk et al., 2013; Navon et al., 2013). Some of these devices have been evaluated in different experimental conditions and with variable results ($P < 0.05$ $r = 0.41$ to 0.96 and $R^2 = 0.86$ to 0.93).

Automatic recording systems present advantages over visual observations however these devices need to be tested and validated to ensure that the obtained data is reliable and accurate. In the past few years the rumination collar (RC) (SCR Engineers, Israel) has frequently been utilized in the literature (Adin et al., 2009; Gregorini et al., 2012; Soriani et al., 2012; Schirmann et al., 2013; Hart et al., 2013). The RC enables the recording of rumination time from sounds recorded by a microphone with a neck collar, which is positioned to hold the RC microphone on the left side of the cow's neck. The characteristic sounds of regurgitation and rumination are recorded, digitally stored, processed and then data presented as rumination time either min / 2 h or min / d (Bar and Solomon, 2010). Previous studies have evaluated the RC under experimental conditions i.e. cows confined in individual pens that are not representative of group housing in farm commercial conditions, and cannot be extrapolated to different environments (Schirmann et al., 2009; Burfeind et al., 2011).

When the RC were evaluated on other environments (under on-farm conditions), evaluation was either not performed against known rumination behavior (Byskov et al., 2014); or the evaluation showed the RC performance to be very poor and inconsistent (Goldhawk et al., 2013; Elischer et al., 2013). Furthermore these previous evaluations of the RC did not use statistical analyses that took into account the repeated measures performed on individual cows.

Although the performance or output of the RC has been under scrutiny in the past years, the consensus seems to be that further evaluation and validation are needed (Schirmann et al., 2009; Burfeind et al., 2011; Elischer et al., 2013; Goldhawk et al., 2013). Therefore the aim of the present study was to compare the rumination activity measured with the RC against that obtained from direct observation and by analysis of video recordings in commercial farm environments with both cubicle-housed and grazing dairy cows.

MATERIALS AND METHODS

Animals

Three Trials were conducted at the University of Edinburgh at Langhill Farm, Roslin, Midlothian, Scotland, UK during 2012 and 2013. The farm has a 240 cow Holstein milking herd. All procedures related to animals were approved by the Veterinary Ethical Review Committee (References: Trial 1 VERC 2011-88, Trial 2 VERC 30/12 and Trial 3 VERC11/13) of the Royal (Dick) School of Veterinary Studies of the University of Edinburgh.

Trial 1. January 2012. Fourteen multiparous milking cows were selected and balanced for DIM (mean ± SEM 104 ± 12 d) and parity (median lactation number (L) = 4). The cows were then randomly allocated to two different groups Group 1 (G1: DIM 103 ± 5.0 d, L = 5) and Group 2 (G2: 105 ± 4.6 d, L = 4), seven cows in each group. Each group was housed in contiguous pens that share identical characteristics: area of feed and water troughs, cubicle/stalls with rubber mattresses top-dressed with sawdust three times a week.

Cows were offered a partial mixed ration (PMR) (1st cut grass silage 46.2 % (fresh weight PMR proportion), wholecrop wheat silage 18.0 %, crimped maize 6.7 %, dairy meal 24.1 % and molasses 5.1 %), with additional concentrate fed to yield in the milking parlor. Water was supplied ad libitum, and the cows were milked twice daily as per standard farm practice.

Trial 2. January 2013. Fourteen multiparous milking cows were selected and balanced for DIM (97 ± 4.3 d) and parity (L = 3). The cows were then randomly allocated to two different groups Group 1 (G1: DIM 96 ± 2.7 d and L = 3) and Group 2 (G2: DIM 99 ± 9.2 d, L = 4), seven cows in each group. Each group was housed in contiguous pens that share identical characteristics: area of feed and water troughs, cubicle/stalls with rubber mattresses top-dressed with sawdust three times a week.

Cows were offered a PMR (1st cut grass silage 44.9 %, wholecrop wheat silage 17.6 %, 2nd cut grass silage 15.6 %, dairy meal 18.5 % and molasses 3.4 %), with additional concentrate fed to yield in the milking parlor. Water was supplied ad libitum, and the cows were milked twice daily as per standard farm practice.

Trial 3. May 2013. Fourteen multiparous milking cows were selected and balanced for DIM (139 ± 4.5 d) and parity (4 ± 0.4 L). The cows were then randomly allocated to two different groups Group 1 (G1: DIM 140 ± 6.3 d, L = 4) and Group 2 (G2: DIM 137 ± 6.8 d, L = 4), seven cows in each group. Cows were grazing a rye grass (*Lolium* perenne) sward during the day and night. In addition, when the cows came in for milking in the afternoon, they were offered a buffer PMR ration (1st cut grass silage 45.5 %, wholecrop wheat silage

35.4 %, Langhill dairy meal 18.9 % and Calcined magnesite 0.3 %). Additional concentrate was fed to yield in the milking parlor. Water was supplied ad libitum, and the cows were milked twice daily as per standard farm practice. The Trial started after a month the cows had been out grazing on pasture.

In all Trials: individual cows were unique to each Trial, cows were divided into two groups to facilitate management routines, e.g., milking and video recording in Trial 1, and to ensure similar parities and DIM between groups of cows in all three Trials. Cows were milked in a 28 / 28 herringbone milking parlor (DeLaval, England UK) approximately at 0500 and 1500. During milking, cows received a minimum of 0.8 kg and a maximum of 6 kg of concentrate a day per cow. All the individuals were clearly identified with a unique number or letter by color spray (Arco Limited, England UK) on either side of the thorax and/or neck so they were easily viewed and recognized. Cows were given two weeks to adapt to the diet, facilities and the RC. All measurements were taken in the third week.

Data collection

In all Trials, a RC (Qwes-HR Lely Ltd., England UK) was fitted to each cow to record rumination. A tag reader was located at the exit of the milking parlor so data from the RC was downloaded to and stored, at least twice a day, after each milking. This prevented overwriting of the data as the RC internal memory capacity has only a 22 h storage capacity. The raw data from the RC was then collated. The output presents rumination in minutes per two hour periods (02:00 h, 04:00 h, 06:00 h or 01:00 h, 03:00 h, 05:00 h, etc.) over a day.

Trial 1 Cow behaviour was recorded using sixteen video cameras (Panasonic WV BP120, Panasonic, UK) with 1/3” fixed iris lenses (Panasonic WV-LF4R5C3AE, Panasonic, UK). The cameras were positioned in key places throughout the shed (fitted to the roof 4.0 and 5.5 m above the ground) so that all cows were viewed and easily identified (by their unique number or letter) at any given time. The area under observation was naturally lit during daylight hours and infrared lighting was used for night time recording. The cameras recorded 24 h a day. On an average day 3 h of cow behavior were missed as the cows left the pens to be milked (around 0500 and 1500). Behavioral measurements were analyzed and recorded using The Observer® software (Noldus Information Technology, 2004, Wageningen, The Netherlands) by one trained observer using the video tapes recorded during the measuring week. Each cow was recorded continuously for periods of 2 h at a time to complete a full 24 h period per week.

Trials 1, 2 and 3. Cow behaviour was recorded by one trained observer using a hand held device, Psion WorkAbout Pro M, (Noldus Information Technology, Wageningen, The Netherlands). Each cow was recorded continuously for periods of 2 h without interfering with their normal behaviour: a) when cows where housed indoors (Trials 1 and 2), the observer was standing in places of the shed where all the behaviors of a specific animal were easily recorded and the observer's presence had no effect on the cow's routine and behaviors i.e. the animal did not change behaviour or moved away from observer. b) when cows were outside grazing on pasture (Trial 3), the observer was standing on the field at a distance (approximately 10 meters) were all the behaviors of a specific animal where easily recorded and the observer's presence had no effect on the cow's routine and behaviors i.e. the animal did not change behaviour or moved away from observer.

Behaviors (eating, drinking, idling and ruminating) were recorded according to the ethogram shown in Table 1. Rumination was defined as: the time a cow spends chewing a regurgitated bolus until it swallows it back. Behaviors were recorded continuously (Martin et al., 1994; Mitlohner et al., 2001) and were defined as being mutually exclusive categories. The 2 h periods recorded were selected so that they matched exactly the period reported by the RC; behaviors were reported in min per 2 h. Behaviors were recorded from available video recordings to complete 24 h period for each cow from a whole week. Direct observations were recorded to match exactly the periods reported by the RC.

Statistical Analysis

Observer reliability. To test the observer reliability when assessing behaviors from the video recordings, the trained observer scored rumination time twice on 20 % of the total observed 2 h periods and the Pearson correlation coefficient between the measurements was calculated.

Relationship between rumination times obtained with RC and analysis of video recordings. For Trial 1 (video recording analysis) a modification of the standard limits of agreement (LoA) methodology was adopted to take account of the multiple observations per individual (Bland and Altman, 1986; Bland and Altman, 2007) and to explore the agreement between the measurements obtained with the RC and analysis of video recordings. When considering the relationship between the two variables a standard linear mixed-effect model was used, to resolve the non-independence associated with the multiple measurements per cow (Paterson and Lello, 2003). In the linear mixed-effect model, which cow that the measurement had come from, was entered as the random effect. Additionally an analysis was made to test whether the slope between RC and analysis of video recordings was different from 1.

Relationship between rumination times obtained with RC and direct observations. For Trial 1 (direct observations measurements only), only one measurement was recorded for each individual cow. Therefore a standard regression analysis and the standard LoA method were used to determine the relationship and agreement between the rumination time obtained by RC and direct observations.

For Trials 2 and 3, the standard linear mixed-effect model and modified LoA method with multiple observations per individual were again used. Additionally an analysis was made to test whether the slope between RC and direct observations was different from 1.

All statistical analysis were carried out using R (R Core Team, 2013) with the linear mixed-effect analysis carried out using the ‘nlme’ package (version 3.1-113), the standard LoA method using “MethComp” package (version 1.22) and a modified version of the LoA with repeated measures as modified by (Nutter B, 2008). Statistical significance was taken as $P < 0.05$.

RESULTS

Observer Reliability. Thirty-three two hour periods (20% of the total 164 2 h observed periods) were analyzed twice. The twice observed 2 h periods reported very similar rumination times (mean = 39 ± 4 and 38 ± 4 min/2 h), with a very strong positive correlation between the rumination times obtained from the twice analyzed periods ($r = 0.99$, $P = 0.001$).

Relationship between rumination times obtained with RC and analysis of Video Recordings. In Trial 1, behavior was recorded in a total of 164 2 h periods from all cows. However only 136 2 h periods, when cows were visible at all times, were used for the analysis to determine the relationship between rumination time recorded by the RC and that obtained from analysis of video recordings. The RC recorded a mean rumination time of 45 ± 2 min / 2 h that was similar to the mean rumination time obtained by analysis of video recordings 46 ± 2 min / 2 h (Table 2). The LoA plot (Fig. 1) shows an evenly distributed scatter of measurements with no patterns and there is no clear tendency of the difference between methods to get either larger or smaller as the averages increase. The RC reported rumination times that were on average 1 min (95 % C.I. - 24 and 27 min) shorter than those recorded by analysis of videos.

Individual plots of the relationships between the two methods showed large variation in the rumination time recorded (R^2 varying from 28.3 % to 97.6 % with slopes from: 0.74 to 1.43, Fig. 2). The variability per individual is best exemplified by cows Cd and T1, with poor agreement for cow Cd and data points that match almost entirely with the line of perfect agreement for cow T1.

If the data from all cows were considered then a significant positive relationship was observed (P = 0.001, Fig. 3), with the slope very close to 1 (slope = 1.02, Table 2). Excluding cow Cd from the analysis made little difference to this (slope = 1.02). In either cases the slope was not different from 1 (P = 0.72)

Relationship between rumination times obtained with RC and direct observations.

In Trial 1, behavior was recorded in a total of 14 2 h periods (one 2 h period per cow). The RC recorded a mean rumination time of 31 ± 5 min / 2 h that was similar to the mean rumination time obtained by direct observations 35 ± 6 min / 2 h. Using the LoA method an evenly distributed scatter of measurements with no patterns was obtained. There was no clear tendency of the difference between methods to get either larger or smaller as the averages increase. The RC reported rumination times that were, on average, 6 min (95 % C.I. -33 to 20 min) shorter than those recorded by direct observations. The standard regression analysis showed a positive relationship (P = 0.001, Fig. 4), with the slope very close to 1 (slope = 1.08, Table 2), when testing, the slope was not different from 1 (P = 0.71).

In Trial 2 behavior was recorded for a total of 28 2 h periods (two 2 h periods per cow). The RC recorded a mean rumination time of 28 ± 4 min / 2 h that was similar to the mean rumination time obtained by direct observations 35 ± 4 min / 2 h. The modified LoA method resulted in an evenly distributed scatter of measurements with no patterns or tendencies. The RC reported rumination times that were on average 3 min (95 % C.I. -32 to 20 min) shorter than those recorded by direct observations. As with Trial 1 a significant positive relationship was observed ($P < 0.001$, Fig. 5), with the slope close to 1 (slope = 0.93, Table 2) the slope was not different from one ($P = 0.63$).

In Trial 3 behavior was recorded in a total of 28 2 h periods (two 2 h periods per cow). The RC recorded a mean rumination time of 39 ± 4 min / 2 h that was similar to the mean rumination time obtained by direct observations 40 ± 5 min / 2 h. As with trials 1 and 2, the modified LoA method showed a scatter of measurements with no patterns and no tendency for the difference between methods to get larger or smaller as the average values increased. However the differences between RC and direct observations were greater than that observed on Trials 1 and 2 (with the 95 % C.I.-51 to 53 min., average 1 min longer RC). A significant positive relationship ($P = 0.02$) was observed between visual observation and the RC. In contrast with Trials 1 and 2, in Trial 3 the slope of this relationship was far from 1 (slope = 0.57, Table 2). However when tested statistically, the slope was not different from 1 ($P = 0.06$).

DISCUSSION

An accurate and reliable measure of rumination time was obtained by analysis of video recordings with acceptable observer reliability. The observer reliability was similar or even higher to studies on which observers scored rumination time either with direct observations

(Schirmann et al., 2009; Goldhawk et al., 2013; Elischer et al., 2013) or from video (Goldhawk et al., 2013).

Our results present the first evaluation on the RC under commercial farm settings for both cows housed indoors and for cows grazing grass on pasture, and using a measurement of rumination time by visual observation directly or by analysis of video recordings. It differs from previous evaluations of the RC in that others used controlled settings, by isolating the animals in individual pens to then be observed (Schirmann et al., 2009), or did not use known values of rumination behavior (Byskov et al., 2014). Also in their previous validation of the RC, Schirmann et al. (2009) and Elischer et al. (2013) reported problems with accurately recording rumination due to the inability of detecting the start and finish of each rumination bout, or due to the fact that the cow's head was not visible to the observer at a distance. In this study such problems were not an issue. For the analysis of video recordings only 2 h periods were used when it was possible for the observer to detect start and finish of the rumination event and when the cow was visible, time slots that did not comply with this were eliminated. Three weeks before the start of the recordings by direct observations, cows were accustomed to the presence of the observer. Furthermore the observer was able to determine start and end of the rumination at all times from a distance far enough as to avoid affecting the cow's natural behavior i.e. changing current behavior or moving away from the observer.

Although the rumination time recorded by analyses of video recordings and the RC were highly correlated, variations between individual cows were observed. Our results were similar to those obtained on previous validations of the RC with recorded rumination times varying from 0 to 90 min / 2 h (Schirmann et al., 2009; Elischer et al., 2013). The variations on the performance of the RC could be explained by variations between cows: for example thicker skin that interfered with the microphone, differences in movement that misplaced the

RC from the neck or variation in behavior when ruminating could have affected the RC data (Elischer et al., 2013; Goldhawk et al., 2013).

The rumination time recorded by direct observations and the RC was highly correlated in Trials 1 and 2. However for Trial 3 the relationship was poor as the slope was far from 1. The results obtained from the indoor trials were very similar, when comparing analysis of video recordings and direct observations. All the Trials showed: data sets with narrow confidence intervals, a tight scatter of dots and an equation line with a slope very close to the line of perfect agreement. The results obtained in Trial 3 with cows outside grazing showed poor agreement between the RC and the direct observations data set as indicated by wider limits of agreement (-51 to + 53 min) shown by the LoA method, wider scatter of dots with wider confidence intervals and a slope far from 1.

Similarities were found across the three trials with previous work performed using cows housed in a pasture based automatic milking system (Elischer et al., 2013), where differences between the two measurements of up to 50 min / 2 h were recorded and the RC in average recorded, shorter (up to 50 min/2 h) rumination times than visual observations.

In general, although no marked tendency was observed, it is nonetheless noteworthy that in several observations, the RC reported rumination time (1 to 25 min / 2 h) when nothing was recorded by the observer (Figs. 3, 4 and 6). Similar results have been reported for the RC used with dairy (Elischer et al., 2013) and beef cattle (Goldhawk et al., 2013). This could be explained by malfunctions in one or more of the RC, or by the fact that positioning of the RC changed due to the free movement of the cows around the pen. Furthermore activities such as: licking and self-grooming, drinking and other background noises (especially when cows on pasture) could have interfered with the recordings made by the RC's microphone. However there was no relationship in this study when data from Trial 3 was analyzed combining multiple behaviors such as rumination and eating, or rumination and drinking with RC output data. Outdoor farm environments inevitably introduce some level of background noise into a recording, and it can be variable and unpredictable (Navon et al., 2013). This background noise could be the cause of errors in the RC when recording rumination, and cancelling noise technology could be used to improve the RC. Possible malfunctions of the RC are not easily detected as there is no standard method to determine if the RC is functioning correctly and that its position on the cow's head is correct at all times. An alternative to correct and control the correct position of the tag in the cow's neck could be the use of a halter instead of a collar.

CONCLUSIONS

Measurements of rumination time obtained with RC proved to be acceptable for the conditions of this study when cows were housed inside the shed. However variations between animals were observed. Our results suggest that the use of the RC in commercial farms can be advised for the determination of rumination activity and are an alternative to visual observations for indoor housed cows. However, the performance of the RC used with cows on pasture grazing was poor. The use of the RC on cows on pasture should not be advised until further research and validation is carried out. Furthermore, published results that use RC in cows at grass should be taken with caution.

Further research is needed to determine a way to ensure that the RC is functioning properly, is placed correctly in the cow's neck at all times and background noises do not interfere with the RC functioning specially with cows at grazing.

FIGURES

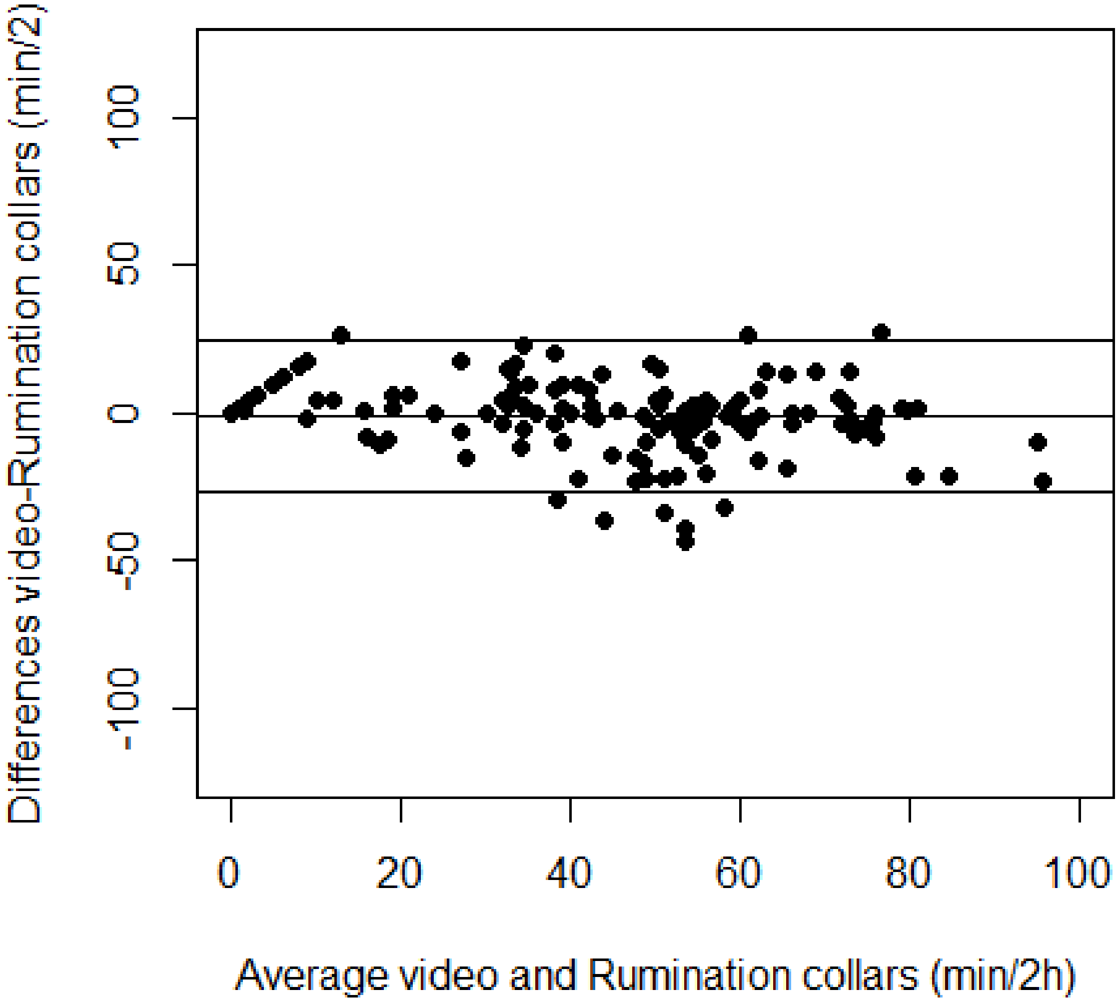


Figure 1: The Limits of Agreement method with multiple observations per individual. The plot shows rumination time (min / 2 h) obtained with the rumination collars and analysis of video recordings in trial 1. A total of 136 2 h periods were recorded from 14 different cows. The lines represent the mean difference between the two methods (central horizontal line, -1min) and the limits of agreement higher (upper horizontal line 25 min) and lower (lower horizontal line - 27 min).

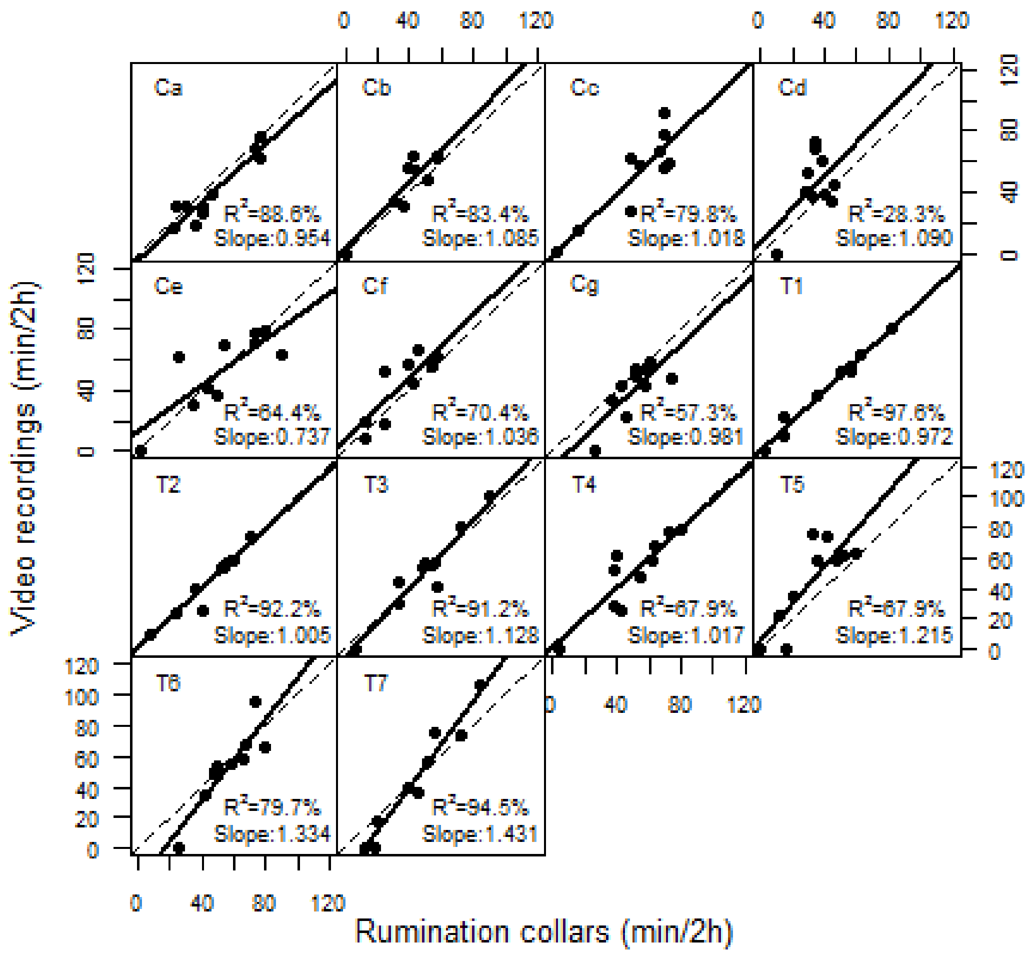


Figure 2: Relationships between rumination time (min / 2 h) measured by rumination collars and analysis of video recordings in Trial 1. Each panel represents data from one individual cow.

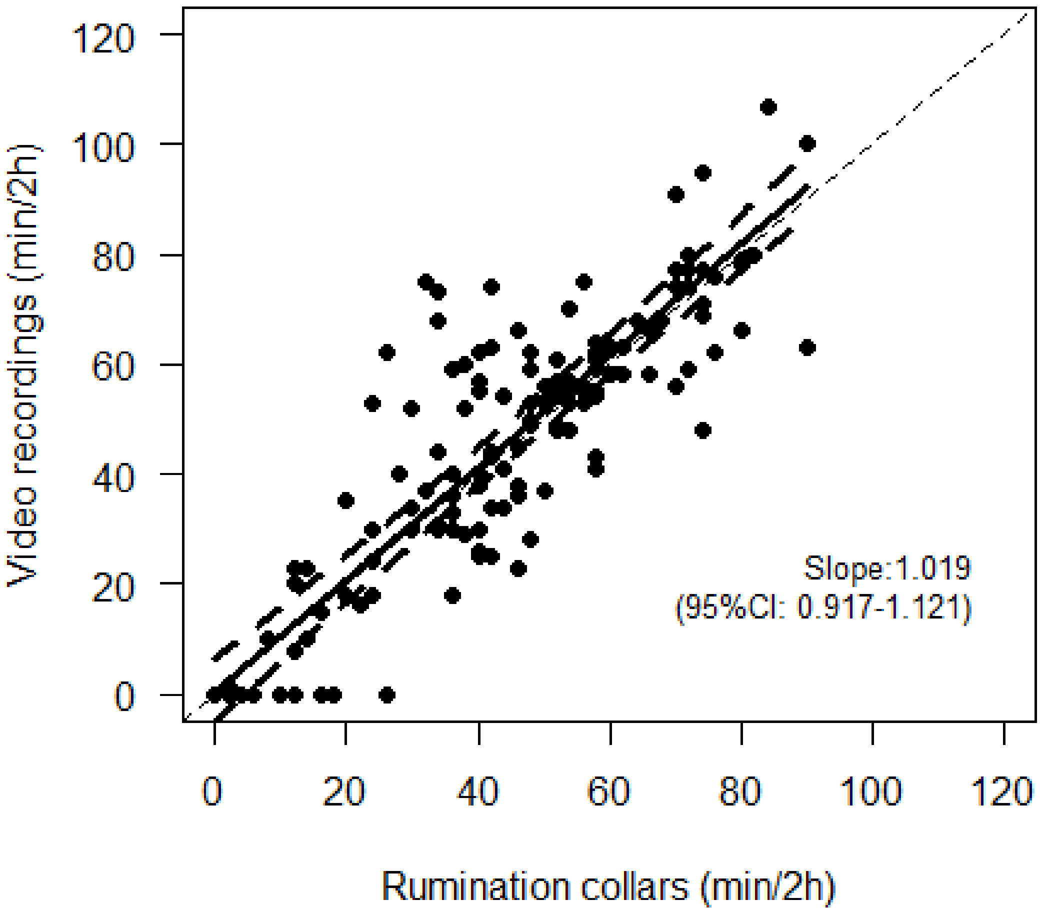


Figure 3: Relationship between rumination time (min / 2 h) measured by rumination collars and analysis of video recordings in Trial 1. A total of 136 2 h periods were recorded from 14 cows. The broken line depicts the line of equality on which all points would lie if RC and analysis of video recordings gave exactly the same reading every time. The solid line shows the equation line and the broken thicker lines show the 95% confidence interval.

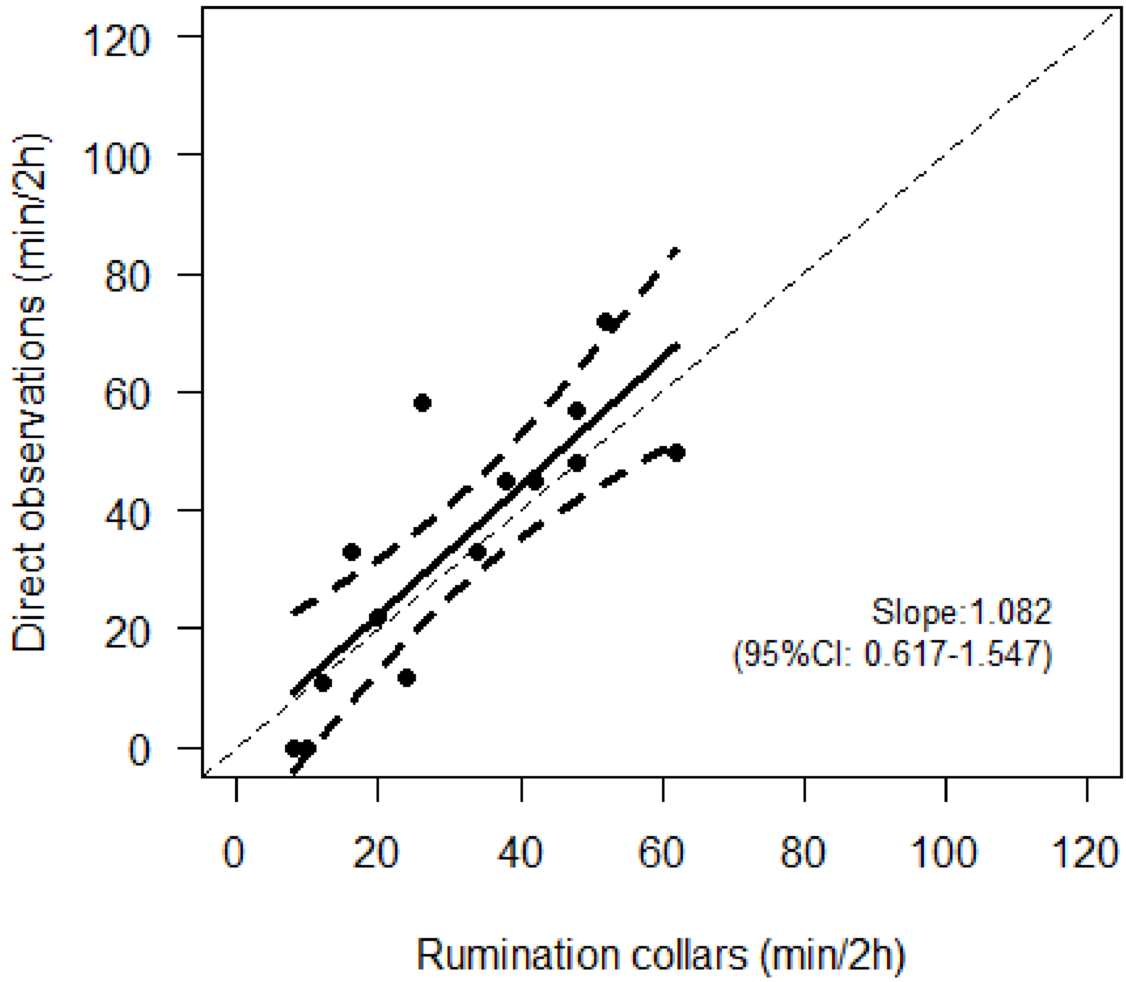
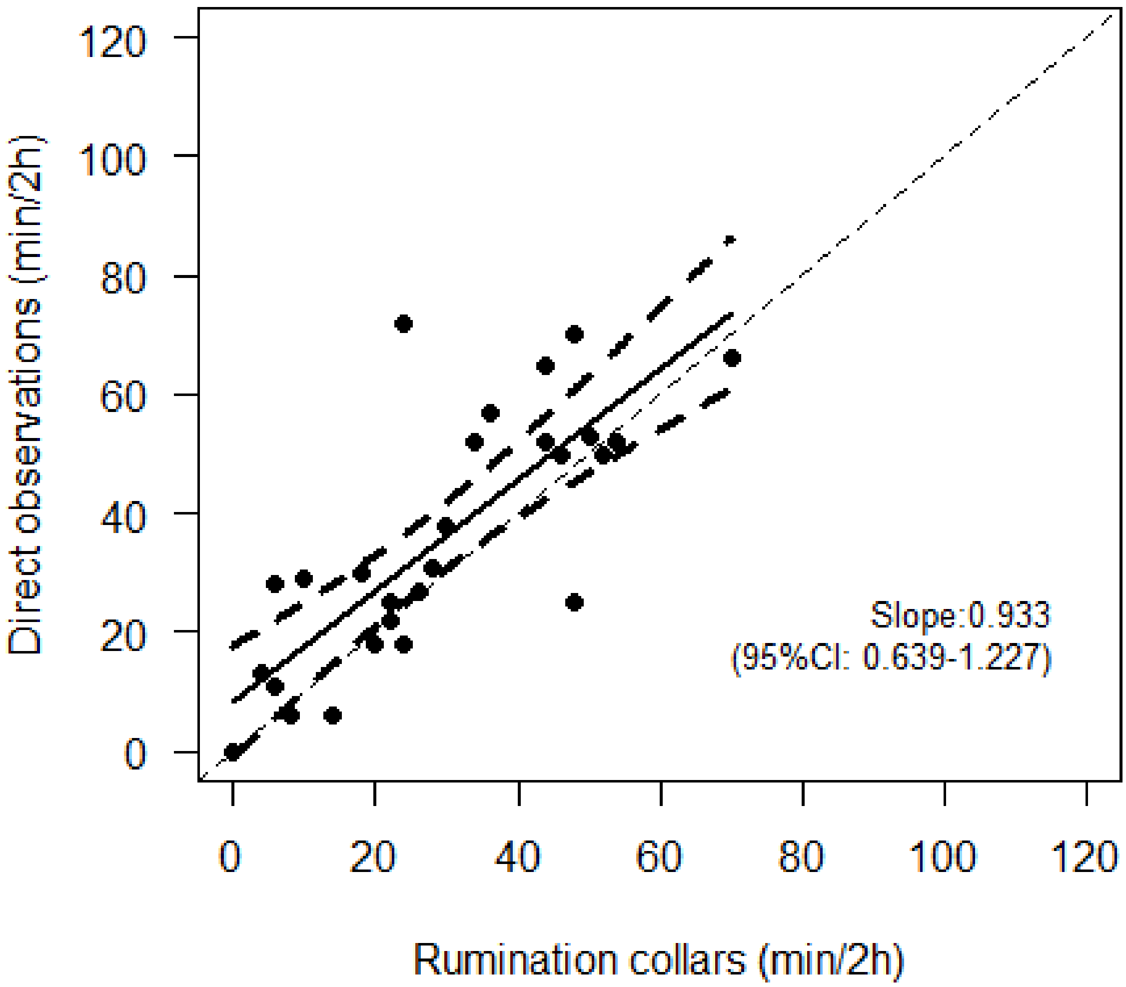


Figure 4: Relationship between rumination time (min / 2 h) measured by rumination collars and direct observations in Trial 1. A total of 14 2 h periods were recorded from 14 cows. The broken line depicts the line of equality, the solid line shows the equation line, and the broken thicker lines show the 95% confidence interval.



402

403 Figure 5: Relationship between rumination time (min / 2 h) measured by rumination collars
404 and analysis of video recordings in Trial 2. A total of 28 2 h periods were recorded from 14
405 cows. The broken line depicts the line of equality, the solid line shows the equation line, and
406 the broken thicker lines show the confidence interval.

407

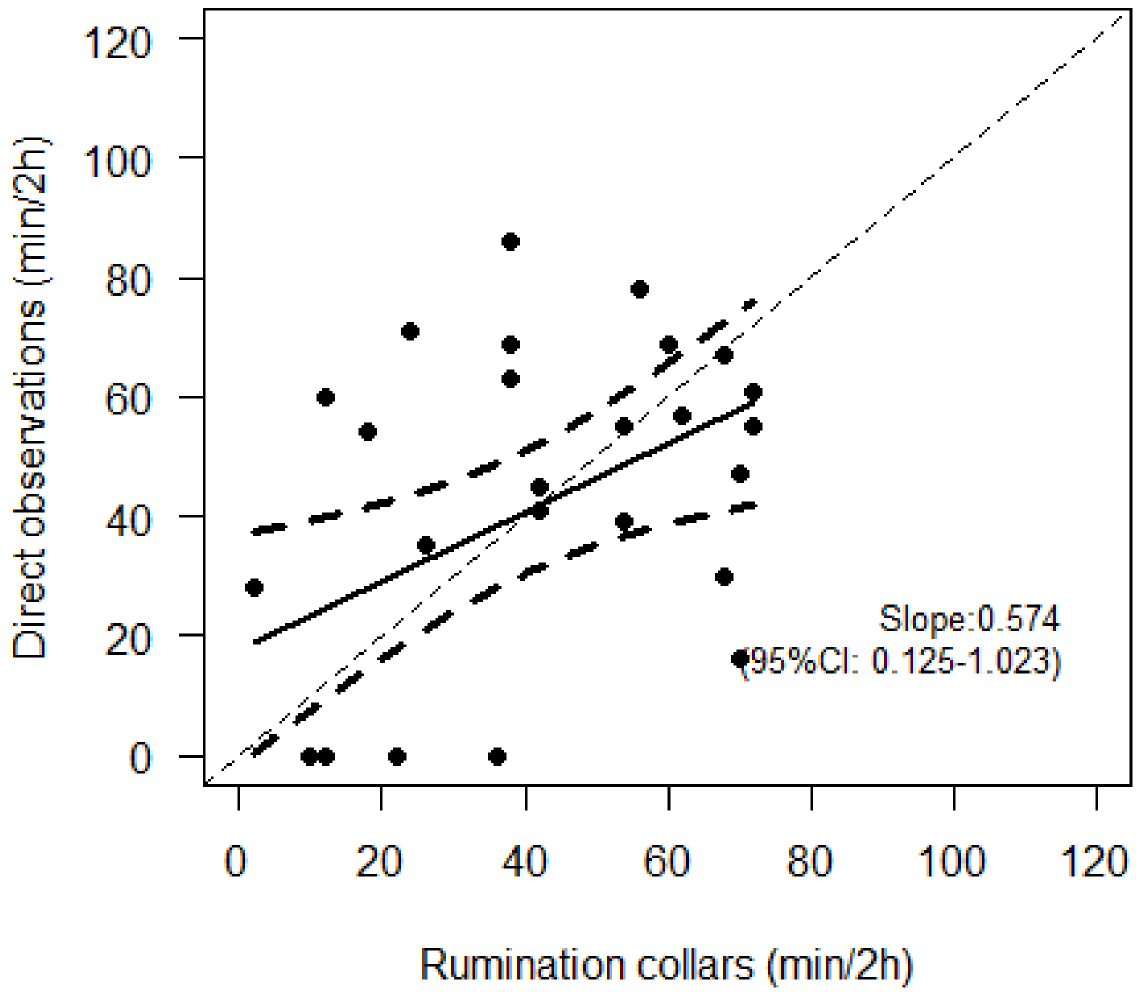


Figure 6: Relationship between rumination time (min / 2 h) measured by rumination collars and analysis of video recordings in Trial 3. A total of 28 2 h periods were recorded from 14 cows. The broken line depicts the line of equality, the solid line shows the equation line, and the broken thicker lines show the 95% confidence interval.

TABLES

Table 1: Behavioral ethogram used in Trials 1-3.

Behavior	Definition
Eating	Head over or in the feed trough
Drinking	Head over or in the water trough
Ruminating	Time the cow spends chewing a regurgitated bolus until it swallows it back
Idling	No ruminating, eating or drinking behavior

Table 2: Analysis of the relationship between rumination times (min / 2 h) obtained with rumination collar (RC) and analysis of video recordings and direct observations: regression analysis (Trial 1 direct observations vs RC), Limits of Agreement method (all trials) and mixed affect model (Trial 1 video recordings vs RC, Trial 2 and 3)

Trial		Regression Analysis lm(Obs~RC)					Limits of Agreement method			Mixed effect model lme(Obs~RC,~1|cowid)		
		N	R^2	Regression Equation	Std.Err	P	Lower limit	Mean	Upper limit		Std.Err.	P
1	Video vs RC	136					-26.92	-1.32	24.27	Video=0.53 + 1.02RC	0.051	< 0.001
1	Direct vs RC	14	0.66	Direct = 0.71 + 1.08RC	0.213	<0.001	-28.54	-3.29	21.98	-	-	
2	Direct vs RC	28					-32.56	-6.36	19.84	Direct=8.24 + 0.93RC	0.136	< 0.001
3	Direct vs RC	28					-51.16	0.93	53.02	Direct=17.66 + 0.57RC	0.207	< 0.05

lm= linear model, lme= linear mixed effects model.

REFERENCES

Adin, G., R. Solomon, M. Nikbachat, A. Zenou, E. Yosef, A. Brosh, A. Shabtay, S. Mabjeesh, I. Halachmi, and J. Miron. 2009. Effect of feeding cows in early lactation with diets differing in roughage-neutral detergent fiber content on intake behavior, rumination, and milk production. J. Dairy Sci. 92(7):3364-3373.

Bar, D., and R. Solomon. 2010. Rumination Collars: What Can They Tell Us. in Proc. First North American Conference on Precision Dairy Management 2010. Vol. Toronto, Canada.

Beauchemin, K. A., S. Zelin, D. Genner, and J. G. Buchanansmith. 1989. An Automatic System for Quantification of Eating and Ruminating Activities of Dairy-Cattle Housed in Stalls. J. Dairy Sci. 72(10):2746-2759.

Bland, J. M., and D. G. Altman. 2007. Agreement between methods of measurement with multiple observations per individual. J. Biopharm. Stat. 17(4):571-582.

Bland, J. M., and D. G. Altman. 1986. Statistical Methods for Assessing Agreement Between Two Methods of Clinical Measurement. Lancet 1(8476):307-310.

Braun, U., L. Troesch, F. Nydegger, and M. Haessig. 2013. Evaluation of eating and rumination behaviour in cows using a noseband pressure sensor. BMC Veterinary Research 9.

Burfeind, O., K. Schirmann, M. von Keyserlingk, D. Veira, D. Weary, and W. Heuwieser. 2011. Technical note: Evaluation of a system for monitoring rumination in heifers and calves. J. Dairy Sci. 94(1):426-430.

Byskov, V., A. Schulze, M. Weisbjerg, B. Markussen, and P. Norgaard. 2014. Recording rumination time by a rumination monitoring system in Jersey heifers fed grass/clover silage and hay at three feeding levels. J. Anim. Sci. 92(3):1110-1118.

Clapham, W. M., J. M. Fedders, K. Beeman, and J. P. Neel. 2011. Acoustic monitoring system to quantify ingestive behavior of free-grazing cattle. Comput Electron Agric 76(1):96-104.

Elischer, M. F., M. E. Arceo, E. L. Karcher, and J. M. Siegford. 2013. Validating the accuracy of activity and rumination monitor data from dairy cows housed in a pasture-based automatic milking system. J. Dairy Sci. 96(10):6412-6422.

Goldhawk, C., K. Schwartzkopf-Genswein, and K. Beauchemin. 2013. Technical Note: Validation of rumination collars for beef cattle. J. Anim. Sci. 91(6):2858-2862.

Gregorini, P., B. DelaRue, K. McLeod, C. Clark, C. Glassey, and J. Jago. 2012. Rumination behavior of grazing dairy cows in response to restricted time at pasture. Livest. Sci. 146(1):95-98.

Hart, K., B. McBride, T. Duffield, and T. DeVries. 2013. Effect of milking frequency on the behavior and productivity of lactating dairy cows. J. Dairy Sci. 96(11):6973-6985.

Kononoff, P. J., H. A. Lehman, and A. J. Heinrichs. 2002. Technical note - A comparison of methods used to measure eating and ruminating activity in confined dairy cattle. J. Dairy Sci. 85(7):1801-1803.

Laca, E. A., and M. F. WallisDeVries. 2000. Acoustic measurement of intake and grazing behaviour of cattle. Grass Forage Sci. 55(2):97-104.

Martin, P, and Bateson P. 1994. Measuring behaviour: an introductory guide. Second Edition ed. Cambridge University Press, Cambridge, UK.

Mitlohner, F. M., J. L. Morrow-Tesch, S. C. Wilson, J. W. Dailey, and J. J. McGlone. 2001. Behavioral sampling techniques for feedlot cattle. J. Anim. Sci. 79(5):1189-1193.

Navon, S., A. Mizrach, A. Hetzroni, and E. D. Ungar. 2013. Automatic recognition of jaw movements in free-ranging cattle, goats and sheep, using acoustic monitoring. Biosys. Eng. 114(4):474-483.

Nutter B. 2008. Bland Altman method to measure agreement with repeated measures, http://stat.ethz.ch/pipermail/r-help/2008-July/166921.html.

Paterson, S., and J. Lello. 2003. Mixed models: getting the best use of parasitological data. Trends Parasitol 19(8):370-375.

R Core Team. 2013. R: A language and environment for statistical computing. in R Foundation for Statistical Computing, Vienna, Austria.

Rutter, S. M., R. A. Champion, and P. D. Penning. 1997. An automatic system to record foraging behaviour in free-ranging ruminants. Appl Anim Behav Sci 54(2-3):185-195.

Schirmann, K., N. Chapinal, D. Weary, L. Vickers, and M. von Keyserlingk. 2013. Short communication: Rumination and feeding behavior before and after calving in dairy cows. J. Dairy Sci. 96(11):7088-7092.

Schirmann, K., M. von Keyserlingk, D. Weary, D. Veira, and W. Heuwieser. 2009. Technical note: Validation of a system for monitoring rumination in dairy cows. J. Dairy Sci. 92(12):6052-6055.

Soriani, N., E. Trevisi, and L. Calamari. 2012. Relationships between rumination time, metabolic conditions, and health status in dairy cows during the transition period. J. Anim. Sci. 90(12):4544-4554.

Umemura, K., T. Wanaka, and T. Ueno. 2009. Technical note: Estimation of feed intake while grazing using a wireless system requiring no halter. J. Dairy Sci. 92(3):996-1000.

Van Soest, P. J. 1994. Nutritional ecology of the ruminant, Second edition. Nutritional ecology of the ruminant, Second edition:xii+476p.

Van Wieren S.E. 1996. Digestive strategies in ruminants and nonrumiants. Ph D Thesis, Wageningen, The Netherlands.

Weary, D., J. Huzzey, and M. von Keyserlingk. 2009. BOARD-INVITED REVIEW: Using behavior to predict and identify ill health in animals. J. Anim. Sci. 87(2):770-777.