Evaluation of an ear tag based accelerometer for monitoring rumination time, chewing cycles and rumination bouts in dairy cows

M. Iwersen[1], S. Reiter[1], V. Schweinzer[1], F. Kickinger[2], M. Öhlschuster[2], L. Lidauer[2], A. Berger[2], W. Auer[2], M. Drillich[1]

[1] Clinical Unit for Herd Health Management in Ruminants, University Clinic for Ruminants, Department for Farm Animals and Veterinary Public Health, University of Veterinary Medicine Vienna, 1210 Vienna, Austria

[2] Smartbow GmbH, 4675 Weibern, Austria

A paper from the Proceedings of the
14th International Conference on Precision Agriculture
June 24 – June 27, 2018
Montreal, Quebec, Canada

Abstract. *The objective of this study was to evaluate the ear tag based accelerometer SMARTBOW (Smartbow, Weibern, Austria) for detecting rumination time, chewing cycles and rumination bouts in dairy cows. For this, the parameters were determined by analyses of video recordings as reference and compared with the results of the accelerometer system. Additionally, the intra- and inter-observer reliability as well as the agreement of direct cow observations and video recordings was tested. Ten Simmental cows were equipped with 10 Hz accelerometer ear tags and kept in a pen separated from the other herd mates. During the study, cows' rumination and other activities were directly observed for 20 h by 2 trained observers. Additionally, cows were video recorded, 24 h a day. After exclusion of unsuitable videos, 2,490 h of cow individual 1-hour video sequences were eligible for further analyses. Out of this, 100 video sequences were randomly selected and analyzed by a trained observer using professional video analyses software. Based on these analyses, half of the data were used for development and testing of the SMARTBOW algorithm, respectively. Inter-and intra-observer reliability as well as the comparison of direct against video observations revealed in high agreements for rumination time and chewing cycles with Pearson correlation coefficients of $r > 0.99$. The rumination time, chewing cycles as well as rumination bouts detected by SMARTBOW were highly associated ($r > 0.99$) with the analyses of video recordings. Testing the algorithm revealed in an underestimation of the average ± standard deviation (SD) rumination time per 1-hour period by SMARTBOW of 17.0 ± 35.3 s (i.e. -1.2%), compared with visual observations. The average number ± SD of chewing cycles and rumination bouts was overestimated by the SMARTBOW system by 59.8 ± 79.6 (i.e. 3.7%) and by 0.5 ± 0.9 (i.e. 1.8%), respectively compared with the video analyses. From a practical and clinical point of view, the detected differences were negligible.*

Keywords. *Cow, accelerometer, rumination, monitoring.*

Introduction

Rumination is essential in the digestive physiology of ruminants and is considered as an important parameter for detecting animals suffering from metabolic diseases and/or indicates imbalances in the diet fed. Rumination can be defined as a process characterized by regurgitation, mastication and re-swallowing of ingesta (Beauchemin 1991), and the number of chews per bolus is associated with the fiber content of the feed. In general, rumination activity can be influenced by several environmental factors, e.g. the nature and amount of feed (Metz 1975; Suzuki et al. 2014), milking schedules and patterns of lighting (Beauchemin 1991).
Adult cows are reported to ruminate approximately 8 h per day in 4 to 24 periods, each of them lasting 10 to 60 min (Gáspárdy et al. 2014) with a physiological limit of rumination time of approximately 10 to 12 h per day (Beauchemin 1991; Welch 1982; Liboreiro et al. 2015).

A continuously monitoring of the rumination activity, e.g. by a sensor system, has the potential to support herd health management decisions. For instance, the association between rumination activity and ruminal pH (Welch 1982) provides the opportunity for an early detection of cows suffering from rumen acidosis. A health index score (HIS) based on rumination and activity data determined by the Hi-Tag rumination monitoring system (SCR Engineers Ltd., Netanya, Israel) was recently evaluated by Stangaferro et al. (2016a, 2016b, 2016c). The HIS showed high sensitivities of 98%, 91% and 89% in detecting animals suffering from displaced abomasum, ketosis and indigestion, respectively, that were detected 0.5 to 3 d before the clinical diagnosis by the farm personnel. The reported sensitivities of the HIS in detecting clinical mastitis and metritis were 58% (81% for mastitis caused by E. coli) and 55%, respectively. Hence, the authors concluded that monitoring rumination time and physical activity could be useful for identifying cows with metabolic and digestive disorders in the early postpartum period. Additionally, the automated rumination and monitoring system was reported to be effective for identifying cows suffering from mastitis caused by E. coli as well as for cows suffering from severe metritis.

Visual observation of rumination activity is regarded as a reliable method and considered as gold-standard, but labor-intensive (Burfeind et al. 2011; Schirmann et al. 2009). As a result, various precision dairy farming technologies for automatic monitoring of rumination activity have been developed. Some devices are recording mastication sounds (Beauchemin et al. 1989; Burfeind et al. 2011; Schirmann et al. 2009; Goldhawk et al. 2013; Ambriz-Vilchis et al. 2015) whereas others are measuring jaw movements (Kononoff et al. 2002; Umemura et al. 2009). Another system consists of an ear tagged device (Bikker et al. 2014; Borchers et al. 2016). Similar to this system, the SMARTBOW Eartag (Smartbow GmbH, Weibern, Austria) used in this study comprises of an acceleration sensor to recognize rumination activity, amongst others.

The primary objective of this study was to evaluate the suitability of the SMARTBOW system for monitoring rumination activity by comparison of the recorded rumination time, jaw movements and rumination bouts with video observations, performed by a trained observer. Additional objectives were to test the intra- and inter-observer reliability as well as the agreement of direct and video recordings.

Materials and Methods

All study-procedures were discussed and approved by the institutional ethics and welfare committee in accordance with Good Scientific Practice guidelines and national legislation (ETK-05/07/15).

Herd Description

The study was conducted from June to August 2015 at the Teaching and Research Farm of the University of Veterinary Medicine, Vienna (Austria), housing approximately 75 Simmental dairy cows in a free-stall barn. The cows were milked twice daily in a tandem milking parlor. The average energy corrected milk yield of the herd in 2015 was 8,569 kg per cow.

Animals and Housing

Ten clinically healthy cows were selected and housed in an extra pen for the duration of the study. Cows of all parities (median lactation number: 2; min: 1; max: 8) in peak lactation (mean DIM ± SD: 73 ± 27 d) were enrolled in the study. Each of the ten cows was equipped with one SMARTBOW Eartag device. Every cow had at least one week to habituate to the ear tag and the study settings before the study started. For a reliable identification during observations, cows were marked with an individual number ranging from 1 to 10 on each side of the croup.

The pen was equipped with 15 cubicles with compact straw-mattresses, top dressed with fresh straw every day. All cows had unlimited access to ten computer-controlled automatic roughage feeders (Insentec Roughage Intake Control System, Hokofarm Group B.V., Marknesse, The Netherlands), which were filled twice a day at 0730 and 1800 with a total mixed ration (TMR) consisting of grass silage, corn silage, grass hay and two concentrate mixtures. The ration was mixed by an automatic feeding system (Trioliet T10, Trioliet B.V., Oldenzaal, The Netherlands). Water was offered ad libitum by two water bowls and cows had access to a salt lick stone.

Study Design

The study was conducted between June and August 2015. In the first part of the study (part 1) data were recorded for developing and refining the algorithms for detecting rumination using the SMARTBOW system. For this, half of the data (i.e. from 50 one-hour video sequences) analyzed from video recordings were communicated to the manufacturer. In the second part of the study (part 2), the refined algorithm was tested on the other half of the analyzed dataset. For this, the dataset was blinded and the manufacturer was asked to communicate the rumination data of a specific cow in a specific timeframe to the authors of this manuscript.

SMARTBOW system and Data Collection

The SMARTBOW Eartag consists of an integrated accelerometer. Commercially available ear tags capture acceleration data once per second (1 Hz), but in this study, ear tags capturing and sending data with a frequency of 10 Hz were used. Data were sent in real time via a receiver device (SMARTBOW Indoor Receiver) to a local server (SMARTBOW Farm Server). Acceleration data are processed by the SMARTBOW Farm Server by using programmed algorithms to detect cow activities, for instance heat and rumination. Rumination data are presented visually on a local computer (desktop client) or on a mobile device (mobile client).

Five Cameras with integrated infrared illuminators (IR Bullet Network Camera Version DS-2CD2632F-I(S), Hikvision, Hangzhou, China) were positioned throughout the pen at a height of approximately 4 m. Three cameras were mounted in front of the cubicles, two additional cameras were directed at the loafing area and at the feeding bins. Cameras recorded 24 h per day. With fading daylight, cameras automatically switched to infrared mode to ensure a continuous observation during night times.

Except for the milking times, cows were housed in the pen for the duration of the study. For the milking process cows left the pen for approximately 1 h in the morning (0630) and 1.5 h in the afternoon (1630) hours. During these times cows were not monitored by direct or video observation. Every cow was identified by its unique number and the rumination process was recognizable in most situations. In preparation of this study, 2 observers were trained for direct and video observations. For this, both observers inspected various ruminating cows together, until the recorded results matched adequately. Cow specific activities (Table 1) were pre-defined to provide a clear definition for various events needed for capturing the activities during the 1 h observation periods. For direct observation, activities were classified into categories (i.e. Eating, Drinking, Ruminating) as shown in the ethogram. Activities seen in the video recordings were classified into "main activities" (i.e. Lying, Standing, Walking) and "optional activities" (i.e. Eating, Drinking, Ruminating, Licking/Scratching). The onset of rumination was defined as the time point when a bolus reached the mouth after regurgitation. The end time was defined as the moment of re-swallowing the bolus (Schirmann et al., 2009). The process from regurgitating until re-swallowing the cud was defined as one "rumination bout".

Table 1. Classification of activities for direct visual observation and analysis of video recordings

Item	Definition
Main activities	
Lying[1]	Cow is lying, carpal- and tarsal joints are on the ground
Standing[1]	Carpal- or tarsal joints are not on the ground
Walking[1]	Cow is doing more than one step in a direction
Optional activities	
Eating[1 2]	Feeding gate opened and cows head in or over the through
Drinking[1 2]	Cows muzzle underwater in the bowl
Ruminating[1 2]	Time a cows spends chewing after a bolus reaches the mouth until it is re-swallowed
Licking / Scratching[1]	Cow is licking an object or another cow / Rhythmical movement of the head during scratching

[1]Activities recorded during video analyses
[2]Activities recorded during direct observations

Observers recorded the start and end point of every rumination bout and counted the number of chewing cycles per bolus (defined as a complete course of movement of the mandible during a single masticatory stroke). The first closure of the mouth, followed by swallowing fluid coming out of the compressed bolus, was defined as the first chewing cycle.

During direct animal observation, observers independently watched every of the 10 cows for 2 1-hour periods, simultaneously. Within an 1-hour observation period the activities of only 1 cow were monitored. Recorded activities were directly entered on tablet devices (E-Board MX049, Proworx, S&T AG, Linz, Austria). By pushing a specific button on the tablet device, activities were documented in an Excel spreadsheet with a unique time signature (as hh:mm:ss:ms). For a reliable comparison of the recorded activities, the system times of the tablet devices, the camera-network and the SMARTBOW system were synchronized at 0000 each day with a Windows time server (Windows Server 2012 R2, Microsoft Corporation, Redmond, USA).

During the study, cows were video recorded for 19 days in total (part 1: 8 d, part 2: 11 d), 24 h a day. Because of problems in recognizing some cows on videos during nighttimes in study part 1, only recordings during daytimes (0800 to 1600) were used for analyses for this part. Excluding the additional video sequences when cows were absent for milking, 570 one-hour cow individual video recording for part 1 and 1,920 h for part 2 were eligible for analyses. Out of this entire pool of video recordings (i.e. 2,490 h) 10 observation periods of 1 hour each per cow (i.e. 100 h in total) were chosen by using a random generator (BiAS, Version 9.07, Epsilon-Verlag, Darmstadt, Germany) for further classification with a professional software for video analyses (Mangold Interact, Mangold International GmbH, Arnstorf, Germany).

In both parts, cows were directly observed by the two observers for 10 h (resulting in 20 h per observer in total), at first. For comparison of direct observations with the video recordings, the 20 1-hour video periods that matched exactly the hours of direct observations were analyzed by the principal author (observer 1) with the Mangold Interact software. To evaluate the inter-observer reliability, the identical video sequences were analyzed by the second observer, too and direct observation results of both observers were compared with each other as well as with video recordings.

Statistical Analyses

All data were captured in Microsoft Excel spreadsheets. For further analyses SPSS (version 24, IBM Corporation, Armonk, USA) was used. The rumination time, chewing cycles and rumination bouts were tested for normal distribution and homogeneity of variance. Pearson correlation coefficients were calculated and paired *t*-tests for rumination time, chewing cycles and rumination bouts (aggregated per 1 h of observations) were performed to test the association between the results obtained from the SMARTBOW system and video analyses as well as for inter- and intra-observer comparisons. Statistical significance for all tests was defined as $P < 0.05$. Averages are reported as mean ± standard deviation (SD) in the manuscript.

To test the intra-observer reliability, 20% of the analyzed video recordings (i.e. 20 1-hour periods) were re-evaluated by observer 1. To test the inter-observer reliability, results from direct observation from both observers were compared and additionally, the second observer analyzed 20 h of video recordings, too to compare them with the results of observer 1.

Pearson correlation coefficients were calculated for rumination time and the number of chewing cycles per bolus determined by the 2 observers (inter-observer reliability), for the twice analyzed periods (intra-observer reliability) as well as for the association between directly observed rumination activity and the results of video analyses. For the comparison of SMARTBOW against direct observations, also the correlations between detected rumination bouts were calculated. Additionally, Pearson correlation coefficients for the rumination time, chewing cycles and rumination bouts estimated by SMARTBOW were calculated.

Statistical analyses were performed separately for part 1 (algorithm development) and part 2 (algorithm testing) of the study to detect possible differences in the calculated parameters between both parts, and thereby testing for possible confounders.

Results

The average dry matter intake per cow and day recorded by the roughage intake control system was 19.6 ± 2.4 kg in part 1 and 20.5 ± 2.2 kg in part 2 of the study.

Observer Reliability and Association between Direct Observations and Video Analyses

The results of the intra- and inter-observer reliability based on 20 one-hour observation periods of direct and video observations are presented in Table 2. All of the comparisons showed a near perfect agreement of $r > 0.99$ ($P < 0.001$).

Table 2. Intra- and Inter-observer reliability as well as the association between direct visual and video observations

Method 1 vs. Method 2	Observation hours	Correlation (r)[1]	Mean ± SD[2]	Difference ± SD	Paired *t*-test	
					Paired *t*	*P*-value
Rumination time (s per h)						
Direct (Obs1)[3] vs. Direct (Obs2)	20	> 0.99	1858.5 ± 953.8 1857.8 ± 954.1	0.8 ± 15.8	0.21	0.83
Video (Obs1) vs. Video (Obs2)	20	> 0.99	1867.2 ± 955.7 1865.8 ± 955.8	1.4 ± 4.6	1.40	0.19
Video (Obs1.1) vs. Video (Obs1.2)	20	> 0.99	1631.8 ± 1052.8 1636.7 ± 1053.5	-4.9 ± 12.4	-1.70	0.10
Direct (Obs1) vs. Video (Obs1)	20	> 0.99	1858.5 ± 953.8 1867.2 ± 955.7	-8.7 ± 28.1	-1.40	0.18
Chewing cycles (n per h)						
Direct (Obs1) vs. Direct (Obs2)	20	> 0.99	2047.6 ± 1075.8 2051.0 ± 1071.8	-3.5 ± 28.2	-0.55	0.59
Video (Obs1) vs. Video (Obs2)	20	> 0.99	2050.7 ± 1066.4 2025.5 ± 1060.2	25.2 ± 26.0	4.34	< 0.01
Video (Obs1.1) vs. Video (Obs1.2)	20	> 0.99	1772.8 ± 1136.3 1775.4 ± 1128.7	-2.6 ± 28.3	-0.41	0.69
Direct (Obs1) vs. Video (Obs1)	20	> 0.99	2047.6 ± 1075.8 2050.7 ± 1066.4	-3.1 ± 37.1	-1.38	0.18

[1]P < 0.001 for all Pearson correlation coefficients
[2]Standard Deviation
[3]Obs1 or Obs2 = Observer 1 or 2, OBS1.1/1.2 = first vs. repeated observation of Observer 1

The t-test resulted in a significant difference (P < 0.01) of approx. 25 chewing cycles per hour between the first and the second observer for the analyzed video sequences. A high agreement was found between the results of direct visual observations and the analyses of video recordings for rumination time and chewing cycles per hour (r = 0.99, P < 0.001, for both).

Rumination Time, Chewing Cycles and Rumination Bouts detected by SMARTBOW and Video Analyses

Similar correlation coefficients of r > 0.99 (P < 0.01) between the SMARTBOW system and the video analyses for rumination time were determined in part 1 and part 2 of the study (Table 3). The average rumination time of approx. 1508 ± 1097 sec per one-hour period detected by visual observation was underestimated by SMARTBOW for 16 ± 77 sec (P = 0.04, Table 3), i.e. 1.2%.

Visually observed chewing cycles were highly correlated (r > 0.99, P < 0.001) with the number of cycles recorded by SMARTBOW (Table 3). No differences of the correlation coefficients determined for the 1st and 2nd Part of the study were observed. On average, SMARTBOW overestimated (P < 0.01) the number of chewing cycles by 61 ± 98 per one-hour period compared with the video observations (Table 3), which corresponds to 3.7%.

Observer 1 detected an average number of 29 ± 21 rumination bouts per cow in a one-hour period (Table 3). In comparison to the average number of observed rumination bouts SMARTBOW slightly underestimated (P = 0.046, Table 3) the number by 0.4 ± 1.9 bouts (i.e.

1.3%), resulting in a high correlation of r > 0.99 (P < 0.001) as presented in Table 3.

Table 3. Relationship between the aggregated rumination time, number of chewing cycles per bolus and number of rumination bouts per hour between SMARTBOW and visual observations by video analysis for part 1 (algorithm development) and part 2 (algorithm testing) of the study

Parameter	Observation hours	Mean ± SD[2]			Paired *t*-test	
		SMARTBOW	Video observation	Difference	Paired *t*	P-value
Rumination time (s per h)						
Part 1	50	1549.8 ± 1063.4	1565.0 ± 1072.8	-15.3 ± 103.3	-1.05	0.30
Part 2	50	1434.2 ± 1130.2	1451.2 ± 1128.8	-17.0 ± 35.3	-3.41	< 0.01
Part 1 + 2	100	1492.0 ± 1093.3	1508.1 ± 1097.0	-16.2 ± 76.8	-2.10	0.04
Chewing cycles (n per h)						
Part 1	50	1782.2 ± 1231.0	1720.3 ± 1185.1	61.8 ± 114.9	3.80	< 0.01
Part 2	50	1668.4 ± 1307.3	1608.6 ± 1257.3	59.8 ± 79.6	5.31	< 0.01
Part 1 + 2	100	1725.3 ± 1264.6	1664.5 ± 1216.8	60.8 ± 98.4	6.18	< 0.01
Rumination bouts (n per h)						
Part 1	50	29.2 ± 19.7	29.5 ± 20.0	-0.3 ± 2.5	-0.84	0.41
Part 2	50	28.0 ± 21.9	28.4 ± 22.0	-0.5 ± 0.9	-3.67	< 0.01
Part 1 + 2	100	28.6 ± 20.7	29.0 ± 20.9	-0.4 ± 1.9	-2.02	0.05

[1]*P* < 0.001 for all correlations
[2]Standard Deviation

Discussion

Direct observation of cows is regarded as the gold standard for monitoring rumination activity in cows. For validation of the accelerometer, cows were monitored by video observation. To test the inter- and intra-observer reliability, direct and video observation results from two observers were compared and video sequences were analyzed a second time by the same observer. Direct observation results were compared with the results of video analyses, to test the similarity of both methods in monitoring the rumination activity. In this study, a high agreement was determined by comparison of human vs. human observations. The comparison of direct visual observations, as well as the comparison of video observations resulted in a high agreement. Previous studies reported similar correlation coefficients of r > 0.98 when rumination time was scored by direct (Schirmann et al. 2009; Goldhawk et al. 2013; Ambriz-Vilchis et al. 2015) or by video observations (Ambriz-Vilchis et al. 2015; Goldhawk et al. 2013). A high agreement was also determined for comparison of video-sequences analyzed a second time by the same observer. This intra-observer reliability is in agreement with results of previous studies by Ambriz-Vilchis et al. (2015) and by Goldhawk et al. (2013), reporting correlations of r = 0.99 (P < 0.01). The duration of rumination and the number of chewing cycles determined by direct visual observation and video observation of the same observer were highly correlated. A similar correlation of r = 0.97 (P = 0.001) was determined in a previous study (Goldhawk et al. 2013). These results indicate that the analysis of video recordings is an appropriate method to assess rumination activity, compared with direct visual observation.

For parts 1 and 2 of the study (i.e. algorithm development and algorithm testing), rumination times recorded by video observation were highly correlated with those detected by SMARTBOW (Table 3). The manufacturer refined their algorithms on the basis of the rumination data of the first part of the study, but the results of the accelerometer showed a similar high agreement in the second part of the study, compared with the data of video observations. Strictly speaking, only the data of the second part of the study should be regarded for the evaluation of the SMARTBOW system. In most of the one-hour periods the ear tag recorded an average rumination time that was slightly lower than the visual observed rumination time (mean difference = -1.2%). There was only one one-hour period where SMARTBOW markedly overestimated the rumination time (+ 592 sec). Whilst a second inspection of this video sequence a failure of the observer could be ruled out, hence, we suppose that this was an interpretation error by the SMARTBOW system, as the affected cow showed high activity by intensively licking on a mineral block in this period. In this video sequence the cow showed rumination activity, but it seems that the algorithm did not recognize the end of the rumination bout as the cow switched to an activity with similar motion patterns (licking) immediately after swallowing the last bolus. Although this was the only video period where the system obviously confused a different activity for rumination activity, single measuring errors due to related activities may occur and should be evaluated in further studies.

Borchers et al. (2016) revealed a slightly lower correlation ($r = 0.97$, $P < 0.01$) between visual observed rumination time with the outcomes of the SMARTBOW system. However, studies are not directly comparable, as they used ear tags based on a 1 Hz technology, while in this study 10 Hz sensors were used. For a different ear-attached system (SensOor; Agis Automatisering BV, Harmelen, The Netherlands), lower correlations of $r = 0.93$ were reported (Bikker et al. 2014; Borchers et al. 2016). For visual observations Bikker et al. (2014) reported a mean percentage of 42.6 ± 6.8% for the totally observed rumination time. Within the same timeframe SensOor detected 42.1 ± 6.9%. Additional studies, investigating rumination-measuring systems (RC, Qwes-HR Lely Ltd., St. Neots, UK) based on differing technologies are those of Ambriz-Vilchis et al. (2015), who detected a lower correlation between observed rumination time and measurements of the recorded mastication sounds ($r = 0.81$, $P < 0.001$). A study that evaluated a similar technology (Hi-Tag, SCR Engineers Ltd., Netanya, Israel) also revealed in a slightly lower correlation ($r = 0.93$, $P < 0.001$) than in this study, for comparison of visual observed rumination time with automated measurements of the system (Schirmann et al. 2009). The Hi-Tag system was tested in beef cattle by Goldhawk et al. (2013), who detected a low correlation for rumination time ($r = 0.41$, $P < 0.001$). Automatically detected rumination time exceeded the visual observed rumination time by 9.8 ± 18.7 min per 2 h observation periods, on average. A further study evaluating the Hi-Tag system for detecting the rumination time in youngstock of different age reported correlations ranging from $r = 0.47$ to 0.88 (Burfeind et al. 2011).

Besides rumination time, the number of chewing cycles recorded by video observations was highly correlated to the number of chewing cycles recorded by SMARTBOW. However, in comparison with the results of video observations SMARTBOW slightly overestimated the number of chewing cycles in nearly every cow. In absolute numbers, chewing cycles per bolus were overestimated by approximately 2 chews, on average. But, from a practical and clinical perspective, this deviation is considered as negligible.

Rumination bouts were well detected by SMARTBOW, as indicated by the high correlation coefficient and the agreement between the automated measurements and the results of video observations (Table 3). Although the paired *t*-test showed significant differences for some of the comparisons, the practical impact is regarded as low.

In summary, based on the determined correlation coefficients, the agreement between the SMARTBOW system and visual observations were excellent for detecting rumination time, chewing cycles as well as for rumination bouts. An early and reliable detection of changes of rumination activity is considered as useful instrument for herd health monitoring, in particular animal nutrition. However, further research has to be done on implementing rumination data into herd management decisions under various field conditions in indoor and outdoor housed cattle.

Conclusion

In this study the SMARTBOW system consisting of a 10 Hz technology was eligible in detecting rumination time, chewing cycles as well as rumination bouts in indoor housed dairy cows. The determined correlation coefficients as well as the agreement between the SMARTBOW system and the results of video analyses were excellent. From a practical and clinical point of view, the detected differences between visual observations and the SMARTBOW systems during algorithm testing in rumination time (-1.2%), chewing cycles (+3.7%) and rumination bouts (-1.8%) are negligible. However, further research is necessary on testing the system under various field conditions and on evaluating the benefit on implementing rumination data into herd management decisions.

Acknowledgements

The authors would like to thank the staff from the Teaching and Research Farm Kremesberg of the University of Veterinary Medicine, Vienna (Austria) for their technical assistance. We would like to thank the Austrian Association for Buiatrics (ÖBG) for funding this study, in part. Stefan Reiter submitted this study as diploma thesis at the University of Veterinary Medicine, Vienna (Austria).

References

Ambriz-Vilchis, V., Jessop, N. S., Fawcett, R. H., Shaw, D. J., & Macrae, A. I. (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*, 98(3), 1750-1758, doi: 10.3168/jds.2014-8565.

Beauchemin, K. A. (1991). Ingestion and mastication of feed by dairy cattle. *Veterinary Clinics of North America: Food Animal Practice*, 7(2), 439-463.

Beauchemin, K. A., Zelin, S., Genner, D., & Buchanan-Smith, J. G. (1989). An automatic system for quantification of eating and ruminating activities of dairy cattle housed in stalls. *Journal of Dairy Science*, 72(10), 2746-2759, doi: 10.3168/jds.S0022-0302(89)79418-2.

Bikker, J. P., van Laar, H., Rump, P., Doorenbos, J., van Meurs, K., Griffioen, G. M., et al. (2014). Technical note: Evaluation of an ear-attached movement sensor to record cow feeding behavior and activity. *Journal of Dairy Science*, 97(5), 2974-2979, doi: 10.3168/jds.2013-7560.

Borchers, M. R., Chang, Y. M., Tsai, I. C., Wadsworth, B. A., & Bewley, J. M. (2016). A validation of technologies monitoring dairy cow feeding, ruminating, and lying behaviors. *Journal of Dairy Science*, 99(9), 7458-7466, doi: 10.3168/jds.2015-10843.

Burfeind, O., Schirmann, K., von Keyserlingk, M. A., Veira, D. M., Weary, D. M., & Heuwieser, W. (2011). Evaluation of a system for monitoring rumination in heifers and calves. *Journal of Dairy Science*, 94(1), 426-430, doi: 10.3168/jds.2010-3239.

Gáspárdy, A., Efrat, G., Bajcsy, Á., & Fekete, S. (2014). Electronic monitoring of rumination activity as an indicator of health status and production traits in high-yielding dairy cows. *Acta Veterinaria Hungarica*, 62(4), 452-462, doi:10.1556/AVet.2014.026.

Goldhawk, C., Schwartzkopf-Genswein, K., & Beauchemin, K. A. (2013). Technical note: validation of rumination collars for beef cattle. *Journal of Animal Science*, 91(6), 2858-2862, doi:10.2527/jas.2012-5908.

Kononoff, P. J., Lehman, H. A., & Heinrichs, A. J. (2002). Technical Note - A comparison of methods used to measure eating and ruminating activity in confined dairy cattle. *Journal of Dairy Science*, 85(7), 1801-1803, doi: 10.3168/jds.S0022-0302(02)74254-9.

Liboreiro, D. N., Machado, K. S., Silva, P. R. B., Maturana, M. M., Nishimura, T. K., Brandão, A. P., et al. (2015). Characterization of peripartum rumination and activity of cows diagnosed with metabolic and uterine diseases. *Journal of Dairy Science*, 98(10), 6812-6827, doi: 10.3168/jds.2014-8947.

Metz, J. H. M. (1975). Time patterns of feeding and rumination in domestic cattle. PhD thesis, Landbouwhogeschool te Wageningen, Wageningen.

Schirmann, K., von Keyserlingk, M. A., Weary, D. M., Veira, D. M., & Heuwieser, W. (2009). Technical note: Validation of a system for monitoring rumination in dairy cows. *Journal of Dairy Science*, 92(12), 6052-6055, doi: 10.3168/jds.2009-2361.

Stangaferro, M. L., Wijma, R., Caixeta, L. S., Al-Abri, M. A., & Giordano, J. O. (2016a). Use of rumination and activity monitoring for the identification of dairy cows with health disorders: Part I. Metabolic and digestive disorders. *Journal of Dairy Science*, 99(9), 7395-7410, doi:10.3168/jds.2016-10907.

Stangaferro, M. L., Wijma, R., Caixeta, L. S., Al-Abri, M. A., & Giordano, J. O. (2016b). Use of rumination and activity monitoring for the identification of dairy cows with health disorders: Part II. Mastitis. *Journal of Dairy Science*, 99(9), 7411-7421, doi:10.3168/jds.2016-10908.

Stangaferro, M. L., Wijma, R., Caixeta, L. S., Al-Abri, M. A., & Giordano, J. O. (2016c). Use of rumination and activity monitoring for the identification of dairy cows with health disorders: Part III. Metritis. *Journal of Dairy Science*, 99(9), 7422-7433, doi:10.3168/jds.2016-11352.

Suzuki, T., Kamiya, Y., Tanaka, M., Hattori, I., Sakaigaichi, T., Terauchi, T., et al. (2014). Effect of fiber content of roughage on energy cost of eating and rumination in Holstein cows. *Animal Feed Science and Technology*, 196, 42-49, doi: 10.1016/j.anifeedsci.2014.07.005.

Umemura, K., Wanaka, T., & Ueno, T. (2009). Technical note: Estimation of feed intake while grazing using a wireless system requiring no halter. *Journal of Dairy Science*, 92(3), 996-1000, doi: 10.3168/jds.2008-1073.

Welch, J. G. (1982). Rumination, particle size and passage from the rumen. *Journal of Animal Science*, 54(4), 885-894, doi:10.2527/jas1982.544885x.