Research article

Evaluation of the RumiWatchSystem for measuring grazing behaviour of cows

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HIGHLIGHTS

- The RumiWatchSystem can successfully monitor behaviour of grazing cows.
- High correlation between RumiWatchSystem and visual observation in determining time budget for different cow activities.
- High correlation between RumiWatchSystem and visual observation in determining grazing bites and rumination chews.
- The RumiWatchSystem was proven to be an accurate research tool for measuring detailed grazing behaviour of cows.

ARTICLE INFO

ABSTRACT

Feeding behaviour is an important parameter of animal performance, health and welfare, as well as reflecting levels and quality of feed available. Previously, sensors were only used for measuring animal feeding behaviour in indoor housing systems. However, sensors such as the RumiWatchSystem can also monitor such behaviour continuously in pasture-based environments. Therefore, the aim of this study was to validate the RumiWatchSystem to record cow activity and feeding behaviour in a pasture-based system. The RumiWatchSystem was evaluated against visual observation across two different experiments. The time duration per hour at grazing, rumination, walking, standing and lying recorded by the RumiWatchSystem was compared to the visual observation data in Experiment 1. Concordance Correlation Coefficient (CCC) values of CCC = 0.96 for grazing, CCC = 0.99 for rumination, CCC = 1.00 for standing and lying and CCC = 0.92 for walking were obtained. The number of grazing and rumination bouts within one hour were also analysed resulting in Cohen's Kappa (κ) = 0.62 and κ = 0.86 for grazing and rumination bouts, respectively. Experiment 2 focused on the validation of grazing bites and rumination chews. The accordance between visual observation and automated measurement by the RumiWatchSystem was high with CCC = 0.78 and CCC = 0.94 for grazing bites and rumination chews, respectively. These results indicate that the RumiWatchSystem is a reliable sensor technology for observing cow activity and feeding behaviour in a pasture based milk production system, and may be used for research purposes in a grazing environment.

1. Introduction

With increasing scale on farms, and declining available labour, there is a requirement for technologies that assist farmers in their day to day management. Animal management involves ensuring the health and welfare of the animals; reacting to certain events in the animal reproductive cycle and improving efficiency in feed provision for conversion into an animal product, such as milk or meat. Especially in a pasture based system the balance between the feed offered and the herd demand needs to be optimized to maximise grass utilisation while simultaneously ensuring that animals are well fed at pasture. Shortage in labour and time to observe animals makes it difficult for farmers to monitor all animals intensely.

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Automated monitoring for quantifying physiological and behavioural parameters, e.g. oestrus, somatic cell count and feeding behaviour, can give an insight into overall health status, important animal events as well as helping with feeding management. For a continuous monitoring of these physiological and behavioural parameters sensor-based, easy-to-use tools for farmers need to be developed.

One of the best indicators of health and welfare of dairy cows is feeding behaviour. A study by Bareille et al. (2003) showed that feed intake was influenced by a number of different diseases such as milk fever, ketosis or hoof lesions. There is a benefit to detect emerging diseases earlier by monitoring the feeding behaviour of dairy cows automatically. Previous research has shown that a decline in rumination time can be used as a reliable predictor of both health and fertility events and is also mentioned to be an indicator for cow stress (Herskin et al., 2004). Feeding behaviour can also be used to optimise grassland management decisions with a focus on increasing animal intake and reducing grass residuals. It is of key importance to measure, manage and allocate accurately the feed available and offered to the cows, irrespective of the farming system in order to optimise farm efficiency and profitability. The estimation of feed intake based on behavioural parameters, such as feeding time or bite frequency, provides valuable information that can be used to manage cows. Pahl et al. (2015) conducted a study in an indoor feeding system to compare feeding and chewing time with measured intake data obtained by weighing of the feeding troughs. They concluded that it was appropriate to use feeding behaviour for estimating intake in barn systems.

Some methods have been developed to predict intake in grass-based systems (Undi et al., 2008), such as the N-alkane-method (Dillon and Stakelum, 1988). This method determines the feed intake by the usage of an orally applied bolus with synthetic faeces marker. These measurements are labour-intensive, time-consuming and invasive, as the cows have to be dosed orally twice a day over a 2-week period. An alternative approach used to determine feed intake was the IGER animal recording system (Mezzalira et al., 2014). This consisted of a noseband sensor that measured jaw movement by electrical resistance (Rutter et al., 1997). It could identify and measure grazing and rumination. However, the maximum recording period of this system was 24 h, and the analysis of the data via the "Graze software" was very laborious (Rutter, 2000). Furthermore, the distribution and commercial support for this technology has ceased in recent years. But a new technology, the RumiWatchSystem may have the potential to improve data capture and replace the IGER animal recording system.

The RumiWatchSystem was initially developed by Nydegger and Bollhalder (2010) at the Swiss Federal Research Institute (Agroscope, Tänikon, Switzerland) for behavioural measurements on cows fed indoors and is commercially distributed by the company (Itin + Hoch GmbH, Liestal, Switzerland) since 2010. It is well established as a sensor technology in indoor housing systems (Ruuska et al., 2016) and has undergone a number of modifications in development as a research and advisory tool (Zehner et al., 2012). Most of the modifications were conducted to optimize the analysis software, the RumiWatch Converter, based on development of different algorithms to analyse the raw data. In a study of Zehner et al. (2017) different versions of the RumiWatch Converter were validated in indoor housing systems against visual observation. Further modifications of applied algorithms in the RumiWatch Converter, such as the definition of each grazing bite, were conducted to record grazing behaviour as feeding behaviour differs in indoor housing systems and pasture-based systems. As it is absolutely critical that any animal behaviour sensor operates correctly in monitoring the appropriate parameters, the objective of this study was to validate an updated and adapted version of the RumiWatchSystem for the measurement of grazing behaviour in a pasture-based milk production system. Two separate experiments were conducted to validate parameters such as grazing, rumination, walking, standing and lying time, as well as grazing bites and rumination chews.

2. Material and methods

Validation of the RumiWatchSystem was conducted in two separate experiments with individual cow herds at Teagasc, Animal and Grassland Research and Innovation Centre (Fermoy, Co. Cork, Ireland, 50°07′N; 8°16′W). Experiments 1 and 2 took place in the periods of 10th to 19th of May 2016 and 31st of May to 2nd of June 2016, respectively. The experimental grazing areas represented permanent grassland with 70% perennial ryegrass and 30% annual meadow grass. This study was part of a larger study where different levels of feed allowance were allocated to dairy cows across different periods of the lactation and for different durations.

2.1. Sensor technology

The RumiWatchSystem consists of two separate devices with associated software packages for managing the sensors (RumiWatch Manager) and analysing data (RumiWatch Converter).

The RumiWatch halter incorporates a noseband pressure sensor, a 3-axis accelerometer as well as a data logger. The noseband sensor comprises an oil-filled tube with a built-in pressure sensor. The pressure inside the tube changes with alternation due to chewing activities and is recorded in a 10 Hz resolution. Those raw data are saved on an integrated 4 GB SD-card for up to 4 months, which is implemented together with the data logger in a protective box on the right side of the halter. On the left side, there is a power supply with two 3.6 V batteries integrated in a similarly constructed box. Based on different pressure signatures of the noseband pressure sensor, the RumiWatch Converter is able to detect jaw movements and classifies them based on frequency and rhythm together with acceleration patterns into grazing bites/chews, rumination chews or any other activity. Additionally, the time duration of those different classifications is recorded. Further information about technical components can be found in Werner et al. (2016), Zehner et al. (2012) and Zehner et al. (2017).

The RumiWatch pedometer consists of a protective plastic box with a 3-axisaccelerometer integrated. Similar to the halter, there is an SD-Card and a data logger connected with the 2 3.6 V batteries built into the box. Acceleration raw data for the x-, y- and z- axis are recorded in a 10 Hz resolution. The RumiWatch Converter is able to classify the acceleration raw data by applying specific algorithms into standing, walking, lying as well as amount of strides. Further information about the development and validation can be found in Alsaaod et al. (2015).

The RumiWatch Manager 2 (V.2.1.0.0) and the RumiWatch Converter (V.0.7.3.36) were used for Experiments 1 and 2 of the current study. There were two different approaches for time resolutions. The 1-min summary data were categorized into different focal behaviour classifications by the RumiWatch Converter. The Converter also created numerical values based on a calculation of the time duration (min per period) of focal behaviours in each of the defined time resolutions, e.g. 5-min, 10 min, 1 h summaries.

The RumiWatch Converter V.0.7.3.36 used three different parameters to monitor and calculate grazing time. Two parameters considered in this study were used to calculate grazing time. EAT1 determined grazing with head position down, EAT2 determined grazing with head position up. Furthermore, there were parameters for grazing and rumination bout behaviour integrated in the RumiWatch Converter V.0.7.3.36 with grazing bouts and rumination bouts. A grazing bout was defined as an event, where grazing was detected for a minimum duration of 7 min and the inter-bout

Table 1
Experimental protocol for data collection of cow behaviour by visual observation.

Day	Time	Observer 1	Observer 2
		Cow numbers	Cow numbers
	09:00–11:00	1,2,3	4,5,6
1	12:00–14:00	4,5,6	1,2,3
	17:00–19:00	1,2,3	4,5,6
	09:00–11:00	7,8,9	10,11,12
2	12:00–14:00	10,11,12	7,8,9
	17:00–19:00	7,8,9	10,11,12
	05:00–07:00	4,5,6	1,2,3
3	11:00–13:00	1,2,3	4,5,6
	19:00–21:00	4,5,6	1,2,3
	05:00–07:00	10,11,12	7,8,9
4	11:00–13:00	7,8,9	10,11,12
	19:00–21:00	10,11,12	7,8,9

interval was defined with a minimum threshold of 7 min. That meant, that if a cow was not showing any grazing behaviour for ≤7 min or she commenced to ruminate, the detection of the grazing bout was stopped. These definitions were similar to those used in a study by Pérez-Ramírez et al. (2009) after Brun et al. (1984). A second bout parameter, a rumination bout was defined as having a minimum duration of 3 min and an inter-bout interval with a minimum threshold of 1 min. The study of Wolfger et al. (2015) applied similar criteria.

2.2. Experiment 1

2.2.1. Animals and treatments

A group of twelve spring calving dairy cows from a herd of 15 in a pasture-based milk production system was used. The cows were on average 91 ± 12 days in milk at the start of the experiment. The group consisted of an equal number of Holstein-Friesian (HF) and Jersey crossbred (JEX) cows with four primiparous[1] and eight multiparous cows[2], ranging in lactation number from 2 to 6. The mean bodyweight was 477 ± 65 kg and the average body condition score (BCS) was 2.8 ± 0.2 ranging from 1 to 5, measured under the Edmonson et al. (1989) scoring system. The average milk yield over the experimental period was 22.5 ± 4.5 kg/cow/day. All cows followed a similar milking routine. Cows were milked twice a day (6:30 h and 14:30 h) and spent approximately $1.5 - 2.0$ h per milking away from the paddock.

Cows were on a grass only diet and received a grass allocation twice daily after milking. Pre- and post-grazing sward height was measured daily with a rising plate meter (diameter 355 mm and 3.2 kg/m^{2}; Jenquip, Fielding, New Zealand). Pre-grazing height of grass averaged 11.9 ± 2.5 cm, while post-grazing height averaged 4.5 ± 0.8 cm during the experimental period. The average experimental paddock area over the experimental period was 0.15 ha. All cows were identifiable by numbers painted on their sides (1–12).

2.2.2. Experimental design

Cow behavioural data was collected by visual observation and by automated recording of the RumiWatchSystem. Two previously trained observers were used to monitor the cows. The cow group

was divided into 4 subgroups of 3 cows each. Each subgroup was observed by each observer on 3 occasions per day over a 4 day period (Table 1). Observations took place over 2-h periods between dawn (05:00) and dusk (21:00) excluding milking times, which extended from 7:00 to 9:00 and 14:00 to 17:00 h.

Visual observation was performed by 1-min scan sampling as used in the study of Büchel and Sundrum (2014). Behavioural data was categorized as feeding behaviour (FB) and activity behaviour (AB). Feeding behaviour was further classified as grazing, ruminating and other activities, while activity behaviour was classified as standing, walking and lying (Beauchemin et al., 1989). The different behaviour classifications are described in Table 2. The data were recorded on a manual spreadsheet and were transferred manually to an electronic spreadsheet (Microsoft Excel Version 2010; Microsoft Corporation, Redmond, USA) for analysis.

With regard to the automated data collection, the RumiWatch-System comprised of two devices, a halter placed on the head and a pedometer placed on the left hind leg. The RumiWatch Manager 2 was used to synchronize both RumiWatch devices to UTC (Universal Time Coordinated) at the beginning of the experiment.

2.2.3. Data preparation

There were 144 h (8640 min) of valid observations. This visually recorded data were assembled in three ways. Firstly the data was assigned to the appropriate classification within the categories of FB and AB at 1-min intervals. Secondly, the time duration of the specific classifications of FB and AB were totalled for 1-h intervals. Finally, the number of started grazing bouts and finished grazing bouts and the number of started rumination bouts and finished rumination bouts were calculated for each 1-h period.

The automatically captured data of the halter and pedometer were downloaded using the RumiWatch Manager 2. For this, the micro USB-port integrated in the sensors was connected via a USB-cable to the computer and the raw data were transferred. Further, the RumiWatch Converter (V.0.7.3.36) was used to convert the raw data into 1-min and 1-h summaries. Those summaries comprised comparable parameters to those outlined above for the visual data (classification at 1-min intervals, duration of specific behaviour classification per hour and numbers of grazing and rumination bouts). For the analysis of grazing time, the total of EAT1TIME and EAT2TIME was calculated.

2.3. Experiment 2

2.3.1. Animals and treatments

The objective of this trial was to validate the RumiWatch noseband sensor for the number of grazing bites and rumination chews. A group of twelve spring calving dairy cows were fitted with Rumi-Watch noseband sensors. All cows were identifiable by numbers (1–12) painted on both sides of each cow. The experiment extended over a 2-day-period with an adjustment period to the noseband sensor of 8 days prior to the starting of the experiment. Two cow breeds were included with 7 Holstein-Friesian (HF) and 5 Jersey crossbreds (JEX). The group consisted of 3 primiparous and 9 multiparous cows, ranging from 2 to 6 parities. Average cow milk yield

Table 2
Definition of different behaviour categories for observers, adapted from Bikker et al. (2014) and Alsaaod et al. (2015).

	Behaviour	Definition
Feeding behaviour	Grazing	Cows' muzzle is located near or above the grass and makes biting motion to ingest grass, or cow's head position up and making chewing motion
	Ruminating	Regurgitation, chewing, salivation and swallowing of ingested grass
	Other activities	Any other movements of the muzzle, which are not associated with grass intake
	Standing	Cow is in an upright position but is not walking
Activity behaviour	Walking	Cow takes at least 3 consecutive strides in the same direction (forward or backward)
	Lying	Cow is resting on the ground (not standing)

Table 3
Experimental protocol for data collection on cow behaviour (rumination chews and grazing bites), by visual observation. Observed cows were monitored in 5-min periods in the stated order ascending or descending by each observer.

Day	Time	Observer 1	Observer 2	Observer 3	Observer 4
		CowNo.	CowNo.	CowNo.	CowNo.
1	09:30–11:30	$1 \rightarrow 6$ $7 \rightarrow 12$	$7 \rightarrow 12$ $1 \rightarrow 6$	$6 \rightarrow 1$ $12 \rightarrow 7$	$12 \rightarrow 7$ $6 \rightarrow 1$
	12.00–14.00	$1 \rightarrow 6$ $7 \rightarrow 12$	$7 \rightarrow 12$ $1 \rightarrow 6$	$6 \rightarrow 1$ $12 \rightarrow 7$	$12 \rightarrow 7$ $6 \rightarrow 1$
	17:00–19:00	$1 \rightarrow 6$ $7 \rightarrow 12$	$7 \rightarrow 12$ $1 \rightarrow 6$	$6 \rightarrow 1$ $12 \rightarrow 7$	$12 \rightarrow 7$ $6 \rightarrow 1$
2	04:30–06:30	$1 \rightarrow 6$ $7 \rightarrow 12$	$7 \rightarrow 12$ $1 \rightarrow 6$	$6 \rightarrow 1$ $12 \rightarrow 7$	$12 \rightarrow 7$ $6 \rightarrow 1$
	11:00–13:00	$1 \rightarrow 6$ $7 \rightarrow 12$	$7 \rightarrow 12$ $1 \rightarrow 6$	$6 \rightarrow 1$ $12 \rightarrow 7$	$12 \rightarrow 7$ $6 \rightarrow 1$
	19:00–21:00	$1 \rightarrow 6$ $7 \rightarrow 12$	$7 \rightarrow 12$ $1 \rightarrow 6$	$6 \rightarrow 1$ $12 \rightarrow 7$	$12 \rightarrow 7$ $6 \rightarrow 1$

over the experimental period was 20.8 ± 4.7 kg/cow/day. Cows had an average body weight of 496 ± 69 kg and a BCS of 2.9 ± 0.2. The cows were on a grass only diet and were maintained in the same paddock throughout the experimental period. They had *ad libitum* access to water, and fresh grass was provided once daily directly after morning milking. Milking times were twice daily (6:30 h and 14:30 h) during which the cows spend 1.5-2.0 h per milking away from the paddock. Pre- and post-grazing sward height was measured with an automated rising plate meter which is a grass measuring device (Grasshopper, True North Technologies, Shannon, Co. Clare, Ireland; (McSweeney et al., 2015)) on one occasion during the experiment. Average pre-grazing and post-grazing height were 14.7 cm and 6.1 cm, respectively, on an experimental area of 0.36 ha.

2.3.2. Experimental design

The accordance between all four observers was measured over two days in 24 5-min periods. Four previously trained observers then monitored one cow per observer for 5-min periods to validate the number of grazing bites and rumination chews. The number of grazing bites and rumination chews was recorded using a handheld computer with a specially programmed application. This application was programmed to record each grazing bite or rumination chew by pressing a button on the handheld computer. Each bite/chew in the 5-min measurement period was then summarized in the output to the total amount of bites/chews per 5 min. A grazing bite was defined as a combination of jaw, tongue and neck movement to rip grass accompanied by a grass biting sound (Bailey et al., 1996). Rumination chews were counted after regurgitation took place and a bolus travelled through the oesophagus to reach the mouth (Schirmann et al., 2009). As in Experiment 1, the observational periods were extended to 2-h periods and occurred three times a day (Table 3). All observations took place between 04:30 and 21:00 h. Every 5-min observation period was alternated with a 5-min break period. Cows were rotated across observers for every 5-min observation period, such that the observer monitored each of the 12 cows during each 2-hour observation period.

2.3.3. Data preparation

The data recorded on the handheld computer included the number of visually observed rumination chews and grazing bites. This data was subsequently totalled within a spreadsheet application. In total 249 observation periods were analysed, which had been collected over the 2-day period. The observation periods consisted of 181 periods of grazing bite observations and 71 periods of rumination chew observations. Data were excluded, when two different behaviour types (grazing bites and rumination chews) were monitored within one 5-min period. Periods where neither grazing bites

nor rumination chews were observed, were also excluded from the data set.

With regard to the data automatically recorded by the Rumi-Watch noseband sensor, these data were classified into the categories of grazing bites and rumination chews. The data were then converted by the RumiWatch Converter (V.0.7.3.36) into 5-min intervals, summarizing the numbers of rumination chews or grazing bites. For analysing rumination chews, the algorithms with the plausibility check function for minimum duration of 3 min were turned off.

2.4. Statistical analysis

Statistical analysis was performed using R version 3.3.1 (R Foundation for Statistical Computing, Vienna, Austria). The following analyses were carried out to assess agreement between the Rumi-WatchSystem and visual observations, depending on the type of data recorded at different time periods.

In Experiment 1, Cohen's Kappa (κ) was calculated to assess agreement between RumiWatchSystem and visual observations when FB and AB were recorded at 1-min resolution (Cohen, 1960). The κ – values were interpreted in a similar manner as by Landis and Koch (1977), where: poor: $\kappa < 0.00$, slight: $\kappa = 0.00$–0.20, fair: $\kappa = 0.21$–0.40, moderate: $\kappa = 0.41$–0.60, substantial: $\kappa = 0.61$–0.80, and almost perfect: $\kappa = 0.81$–1.00.

The percentage agreement (PA) of the 1-min resolution data for both categories of FB and AB and specific classifications, e.g. grazing, rumination, standing, walking, etc. recorded by visual observation and RumiWatchSystem was computed using the following formula, used by Martin et al. (1993):

$$PA[\%] = \frac{total \ numbers \ of \ agreement}{total \ numbers \ of \ agreement + total \ numbers \ of \ disagreement} \times 100$$

A number of tests were conducted on the variables with numeric values to assess agreement between data of the RumiWatchSystem and visual observations. The behavioural data from the RumiWatch noseband sensor and from the pedometer were subjected to a graphical analysis in a Bland-Altman-Plot and a Spearman's Rank correlation (r_s) and a concordance correlation coefficient (CCC) was calculated, using the U-statistics (Carrasco et al., 2007). Interpretation of r_s-values and CCC were based on criteria defined by Hinkle et al. (2003) as follows: Negligible = 0.0–0.3, low = 0.3–0.5, moderate = 0.5–0.7, high = 0.7–0.9 and very high = 0.9–1.00.

The Bland-Altman-Plots demonstrated the agreement between both measurement methods. This was conducted by plotting the differences (automated measurement − visual observation) against the means of visual observation and automated measurement. The Bland-Altman-analysis indicated the mean differences (bias), between the paired automatically recorded and visually observed

values, with 95%-confidence intervals (CI). It also displayed the lower and upper limits of agreement along with their relative 95%-confidence intervals. The limits of agreement were calculated as ± 1.96*standard deviation from mean difference. Although the parameters were not normally distributed, the Bland-Altman-plots were used, as the differences between the paired values followed a normal distribution. In addition, a method to determine significant differences between two measurements by Giavarina (2015) was also applied on the Bland-Altman-analysis. The bias (or mean difference) was considered to be significant when the line of equality was not within the 95% CI of the mean difference. Therefore, a significant under- or overestimation was declared when the line of equality was not included in the 95% CI of the mean difference.

For the validation of bouts (grazing and rumination), there were values between 0 and 2 for bouts started or finished within each 1-h period measured. Therefore, these values were treated as ordinal variables. The agreement for grazing and ruminating bouts was assessed using weighed kappa statistics and percentage agreement, as explained above.

In Experiment 2 grazing bites and rumination chews were counted by human observers during 5-min periods. Agreement between every paired observer was evaluated using CCC and among all observers via overall CCC. Number of grazing bites and rumination chews per 5-min period were analysed using the same methods for numeric variables as described in Experiment 1, including Spearman's Rank correlation, CCC and Bland-Altman-Analysis.

3. Results

3.1. Experiment 1

The comparison of categorical data of the noseband sensor and of the pedometer is shown in Table 4. The Cohen's Kappa value was $\kappa = 0.84$ for the visual feeding behaviour measurements compared with the noseband sensor and $\kappa = 0.89$ for the visual activity measurements compared to the pedometer. Using an interpretation of Landis and Koch (1977), these results indicate an almost perfect agreement of visual and automatically recorded data on a 1-min resolution. This result is supported by the overall agreement of 91.1% for the noseband sensor and 95% for the pedometer.

The evaluation of 1-h summaries of feeding behaviour measured by the visual observation and by the noseband sensor is presented in Fig. 1 and Table 5. Grazing was detected by visual observation as having occurred for 40.5 min/h (median), while grazing time detected by the automated sensor system was recorded with a median of 47 min/hour. A slight overestimation of the automated system in grazing min per hour is displayed in Fig. 1(a). According to Bland-Altman-Statistics the mean difference was 4.41 min/hour, and this overestimation is shown as the solid line in Fig. 1(a). The correlation of $r_s = 0.96$ and a CCC = 0.96 is classified as very high for determine grazing time.

The comparison of rumination time measured by visual observation and by the automated method is shown in Fig. 1(b) and Table 5. The correlation of $r_s = 0.98$ and a CCC = 0.99 is very high. The automated system recorded a range of measured min of rumination between 0 and 59, with a median of 0. Alternatively, the observers recorded a range from 0 to 57 min with a median of 2 min rumination per hour. In Table 5 the analysis of the Bland-Altman-Plot is presented. The bias of 0.03 min/hour along with the 95% CI of −3.04 and 3.10 demonstrated a perfect agreement between the automated system and the observers. The mean of all values was completely accurate and 95% of all recorded values distributed themselves in a difference range of ± 3 min/hour.
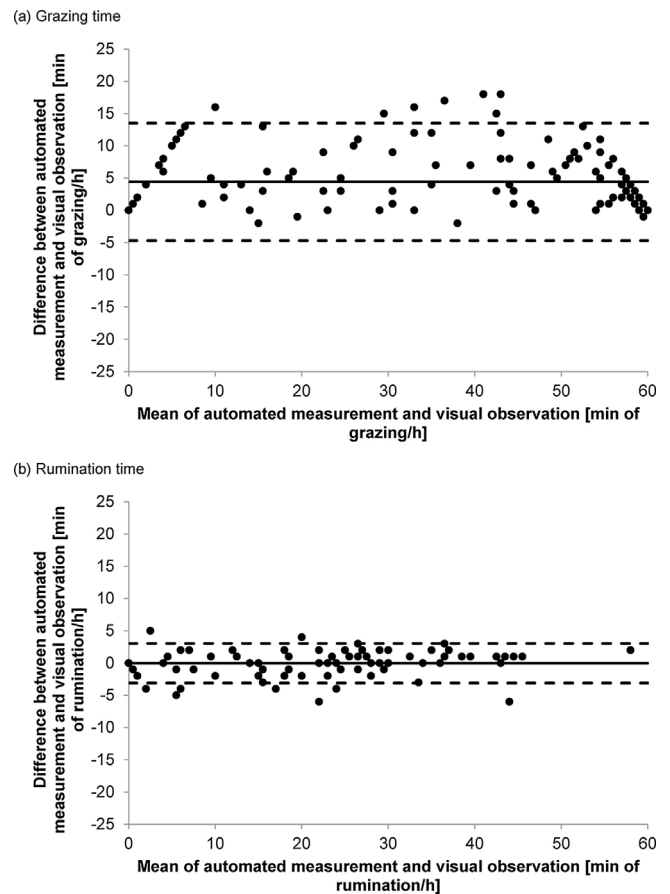
Fig. 1. Agreement of automated RumiWatch noseband sensor measurements and visual observations of feeding behaviour (a) grazing and (b) rumination time in 1-h periods, displayed in Bland-Altman-plots (solid line indicates the mean difference; dashed lines indicate upper and lower 95% limits of agreement).

The total agreement for measuring started and finished grazing bouts within 1-h periods was PA = 84.7% and PA = 85.4%, respectively, whereas the agreement for rumination bouts started and finished was PA = 93.1% and PA = 93.8%. The weighed kappa values showed a moderate agreement between visual and automated measurement with values of $\kappa = 0.62$ and $\kappa = 0.66$ for grazing bouts started and finished, respectively. The rumination bouts showed improved performance, with an almost perfect agreement of $\kappa = 0.86$ for bouts started and bouts finished.

The validation of the pedometer in terms of measuring activity behaviour in a pasture-based system is shown in Fig. 2. Standing time and lying time were determined accurately by the sensor system with a correlation of $r_s = 0.99$, while walking time was less accurately determined by the sensor with a correlation of $r_s = 0.77$. There were less minutes per hour of walking detected in comparison to standing and lying. The median of walking time was 1 min for visual observation and ranged from 0 to 18 min per hour whereas the automated system recorded 2 min per hour, ranging from 0 to 17 min per hour. Grazing time was significantly overestimated and time at other activities was significantly underestimated. Significant differences of bias were also observed between the pedometer and visual recordings in standing time and walking time (Table 5).

3.2. Experiment 2

In this experiment the accuracy of the RumiWatchSystem in measuring grazing bites and rumination chews was examined. The degree of agreement between observers was analysed initially

Table 4

Cohen's Kappa (κ) and percentage agreement between visual observations and automated measurements by RumiWatch for feeding and activity behaviour on a 1-min resolution.

Category	Cohen's κ	Agreement between visual and automated measurement (%)	Classification	Agreement between visual and automated measurement (%)
Feeding behaviour (Grazing, Ruminating, Other Activities)	0.84	91.1	Grazing	91.5
			Ruminating	94.3
			Other Activities	81.4
Activity behaviour (Standing, Walking, Lying)	0.89	95.0	Standing	96.3
			Walking	95.4
			Lying	98.7

Table 5

Spearman's rho (r_s), Concordance Correlation Coefficient (CCC), and Bland-Altman-analysis (Bias, upper and lower 95% limits of agreement with 95% CI) of automated measurements versus visual observations in a 1-h resolution for different behaviour classifications.

Behaviour time in min/h	r_s	CCC	Bias (95% CI)	Lower (95% CI)	Upper (95% CI)
Grazing	0.96	0.96	4.41 (3.64; 5.17)	−4.69 (−6.02; −3.37)	13.51 (12.19; 14.84)
Rumination	0.98	0.99	−0.03* (−0.29; 0.22)	−3.10 (−3.55; −2.66)	3.10 (2.59; 3.48)
Other activities	0.91	0.90	−4.38 (−5.12; −3.63)	−13.20 (−14.49; −11.92)	4.45 (3.17; 5.74)
Standing	0.97	1.00	−0.69 (−0.92; −0.47)	−3.35 (−3.74; −2.96)	1.96 (1.57; 2.35)
Lying	0.99	1.00	0.05* (−0.07; 0.17)	−1.35 (−1.55; −1.15)	1.45 (1.24; 1.65)
Walking	0.78	0.92	0.85 (0.63; 1.06)	−1.71 (−2.08; −1.33)	3.40 (3.02; 3.77)

* = no significant over-estimation or under-estimation between automated system and visual observation
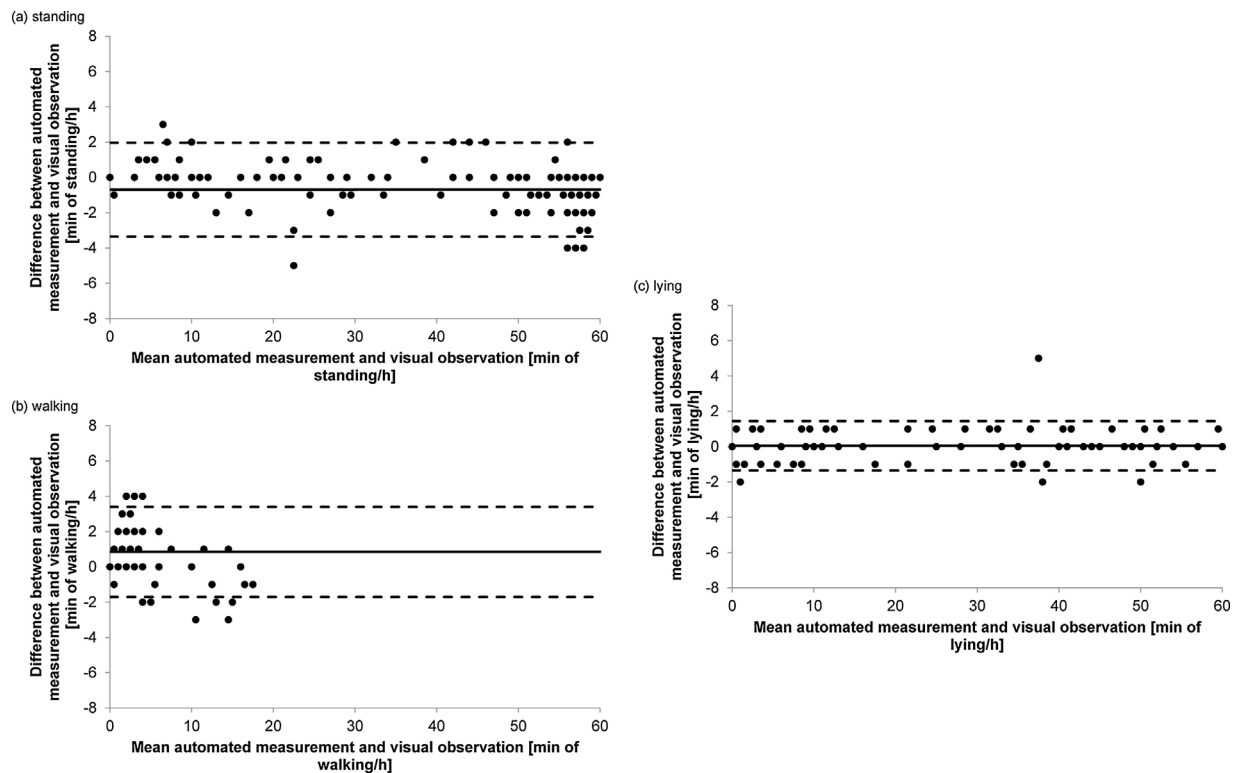
Fig. 2. Agreement of automated RumiWatch pedometer measurements and visual observations for activity behaviour (a) standing; (b) walking; (c) lying in 1-h periods displayed in Bland-Altman-plots (solid line indicates the mean difference; dashed lines indicate upper and lower 95% limits of agreement).
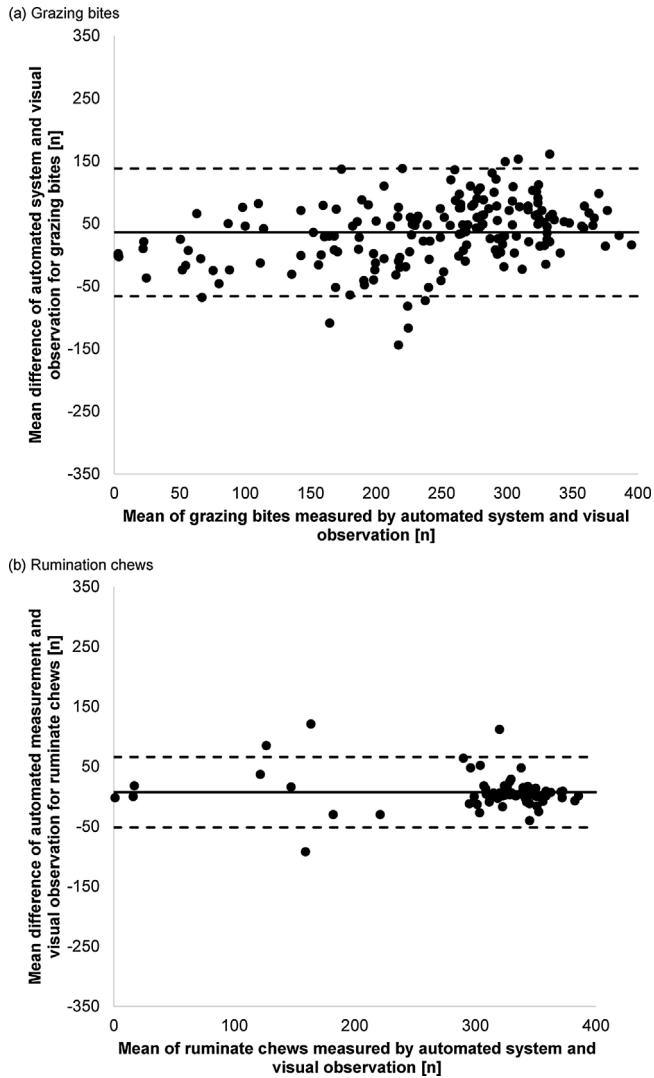
(Table 6). The CCC-values determined for grazing bites and rumination chews were CCC = 0.98 and CCC = 1.00 respectively, which demonstrated a very high agreement between all four observers.

The comparison between the automated system and visual observations in measuring grazing bites are presented in Fig. 3a) and Table 7. The visually counted grazing bites ranged from 0 to 387 per 5-min period, with a median of 232 bites. However, the RumiWatchSystem recorded grazing bites between 0 and 419, with a median of 280 bites. The Bland-Altman-Plot showed that the automated measurement slightly overestimated the numbers of grazing bites. A bias of 36 grazing bites/5 min, with a lower 95% limit of agreement of −66 grazing bites/5 min and an upper 95%

Table 6

Concordance Correlation Coefficient (CCC) for each observer paired with all observers and overall CCC between all four observers in measuring grazing bites and rumination chews.

Behaviour [n/5 min]	CCC				Overall CCC
	Observer 1	Observer 2	Observer 3	Observer 4	
Grazing bites	1			0.97	0.99	
	2	0.97		0.99	1.00	0.98
	3				0.99	
Rumination chews	1			1.00	0.99	
	2	1.00		0.99	0.99	1.00
	3				0.98	

(a) Grazing bites

(b) Rumination chews

Fig. 3. Agreement of automated RumiWatch noseband sensor measurements and visual observations for (a) grazing bites and (b) rumination chews, in 5-min period, displayed in Bland-Altman-plots (solid line indicates the mean difference; dashed lines indicate upper and lower 95% limits of agreement).

limit of agreement of 138 grazing bites/5 min confirmed the significant overestimation of grazing bites by the RumiWatchSystem. Overall, the agreement for grazing bites between the two measurement approaches for grazing bites was high, with $r_s = 0.81$ and a CCC = 0.78 (Table 7).

The evaluation of the measured rumination chews by visual and automated recordings demonstrated positive results as shown in Fig. 3(b). The visually counted rumination chews ranged from 2 to 386 chews/5-min period with a median of 323 chews. Alternatively, the RumiWatchSystem recorded a median of 330 rumination chews/5 min. The agreement between observer and automated system is higher compared to that for grazing bites, with a correlation of r = 0.81 and a CCC = 0.94. The Bland-Altman-plot of Fig. 3(b) also illustrated graphically, that the mean difference between both measurement methods is very small with a value of 7.24 rumination chews per 5-min period. Limits of agreement (dashed lines in Fig. 3(b) indicate that the mean differences between automated measurement and visual observation lie between −51.44 and 65.92 chews per 5-min period.

4. Discussion

4.1. Experiment 1

The automated measurement of grazing time by the Rumi-WatchSystem was compared with visual observation and a high level of accuracy with a very high correlation of $r_s = 0.96$ was observed. The correlation was slightly higher than that of other systems used to detect feeding behaviour in the study of Borchers et al. (2016). In that study, an r = 0.88 and CCC = 0.82 was established for the CowManager 'SensOor' system (Agis, Harmelen, Netherlands) and r = 0.93 and CCC = 0.79 for the 'Track A Cow' system (ENGS, Rosh Pina, Israel). The results in the current study also indicated that the RumiWatch sensor slightly overestimated grazing time in comparison to visual observation. When the parameter 'EAT1TIME' (head position down) was considered in isolation, the correlation was increased to $r_s = 0.97$ and CCC = 0.99. This showed that the parameter 'EAT2TIME' (head position up) may have included some behaviours which should not be considered as feeding behaviours (e.g. licking). Thus, it may be beneficial to define in greater detail, the behaviours that should be included in the different output parameters of the RumiWatch Converter.

Rumination time was not significantly different between the RumiWatch noseband sensor and visual observation. This result is comparable to a study of Kröger et al. (2016), in which the noseband sensor was validated for different feeding regimes in an indoor situation. Furthermore, a study of Borchers et al. (2016) showed the RumiWatchSystem to be slightly more accurate (CCC = 0.99) than the Smartbow system (Smartbow GmbH, Jutogasse, Austria) (CCC = 0.96) in detecting rumination time.

Although the applied algorithms of the RumiWatch Converter differed depending on the chosen output resolution, the accuracy in 1-min summaries and 1-h summaries was very high. For 1-min summaries the challenge for the algorithms was to evaluate each minute separately without any major plausibility checks on time periods before or after the measured minute. Additionally, error

Table 7

Spearman's rho (r_s), Concordance Correlation Coefficient (CCC), and Bland-Altman- analysis (Bias, upper and lower 95% limits of agreement with 95% CI) of automated measurements against visual observations of grazing bites and rumination chews in 5-min periods.

Behaviour (n./5 min)	r_s	CCC	Bias (95% CI)	Lower (95% CI)	Upper (95% CI)
Grazing bites	0.81	0.78	36.01 (28.36; 43.66)	−66.16 (−79.41; −52.93)	138.19 (124.95; 151.44)
Rumination chews	0.81	0.94	7.24 (−0.15; −14.33)	−51.44 (−63.72; −39.17)	65.92 (53.64; 78.19)

detected between automated and visual observations has potential to be more obvious with 1-min summaries than 1-h summaries, as some of the errors may be compensated for, in the totalling of the 60 min (1-h) value. While the high resolution of 1-min recording might not be as important for a commercial application, the benefit for research purposes is significant. Particularly, in behavioural research, the reaction to treatments on a very high time resolution is valuable. Visual observations, on the other hand, are more difficult due to the persons and time commitment required, as well as the reduced practicability of conducting high resolution 1-min scan sampling during night hours. Therefore, an automated measurement system would allow increased measurement and adds functionality to many of the experiments conducted on an on-going basis.

Due to the experimental set up used for validating bout parameters against visual observations there were limitations for the automated system in using the plausibility algorithms. The plausibility checks can be performed best on continuous data. However, the short periods of 1-h observations as used in this study accumulated too many cut-off points. Therefore, the results of a moderate agreement between visual and automated measurement might be explained in this overall context. It is likely that with continuous observations over extended periods of time, those errors of falsely allocated started or finished bouts within 1-h periods would be reduced.

The results of the RumiWatch pedometer were very accurate in detecting standing and lying behaviours. Alsaaod et al. (2015) described and validated the algorithm for the RumiWatch pedometer in their publication and achieved similar accurate results for standing and lying times. The accuracy of detecting walking correctly in the current study was weaker with $r_s = 0.78$ than the other classifications of standing with $r_s = 0.97$ and lying with $r_s = 0.99$. This may be due to the fact that behaviours of lying and standing are more easily detected, and therefore more correctly detected than walking behaviour.

4.2. Experiment 2

The inter-observer reliability was successfully tested to ensure the validity of the results. The overall result among all observers for grazing and rumination was indicated by a CCC = 0.98 and a CCC = 1.00, respectively. Similar results were considered by Schirmann et al. (2009) to be a sufficiently accurate reference to be used as a ground truth in place of visual observation to validate another sensor system. Furthermore, the observational periods in the current study were adjusted from 10 min periods as outlined in Werner et al. (2016) to 5 min periods. This was to ensure maximum concentration by the observer with potentially greater accuracy in counting all grazing bites. Additionally, the focus was placed on grazing bites and rumination chews to improve reliability. Recording every individual jaw movement (e.g. licking, chewing, etc.) was identified as challenging for the observers.

The RumiWatchSystem slightly overestimated the number of grazing bites. This may be due to the noseband sensor being very sensitive in detecting pressure differences. However, an error in visual observation of grazing bites was also detected. This was likely due to the high frequency of grazing bites. Therefore the true or correct number of grazing bites may lie between the values recorded by automated measurement and visual observation. A study by Champion et al. (1997) did consider that detection of grazing bites by the automated system may be more accurate than detection by visual observation. A further study by Delagarde et al. (1999) also showed, the RumiWatchSystem to be as strongly correlated to visual observation in recording number of bites per min as the audio recording system they used in their study with the R^2 values ranging from 0.72 to 0.98.

In a recently published study by Kröger et al. (2016), the RumiWatchSystem was compared to visual observation in terms of accuracy in capturing rumination chews at 10-min resolution, and a CCC of 0.92 was observed. In the current study, a CCC value of 0.94 was observed for a similar comparison. This represented a slight increase in accuracy, which may be a consequence of an updated version of the RumiWatch Converter used in the current study. However, it is also true that the diet differed in both studies, with a feeding regime including roughage, concentrate and a mixed diet being used in the study of Kröger et al. (2016) while a grass diet was predominant in this study. The observational periods also differed between the studies, with the Kröger et al. (2016) and current studies using 10-min and 5-min resolutions, respectively. As the plausibility checks for rumination are based on continuous data the threshold of a minimum of 3 min to detect rumination had to be turned off. Therefore, the results of the two studies are not entirely comparable. For recording of continuous data over long-term periods, this plausibility check function should not influence the accuracy in detecting rumination chews.

In contrast to most commercially available systems in use on-farm, the cost of the RumiWatchSystem and its application involving a halter might not be feasible for widespread use on farms. However, as a research tool it could be very valuable. With the wide ability of recording every jaw movement, the specific differentiation in grazing bites and rumination chews, as well as the quantification of time durations of rumination and grazing, the RumiWatchSystem is a unique tool for measuring grazing behaviour long-term. With further development, it may be suitable to estimate feed intake of dairy cows on pasture, based on measuring bites and chews. As Berckmans (2006) mentioned, visual observation can represent a limiting factor in behavioural research, due to the necessity for restricted observation periods and a high demand in labour. Therefore, the availability of an accurate and reliable automated technology may be very useful and appropriate.

5. Conclusions

Overall, the results indicated that the RumiWatchSystem showed a high level of accuracy in measuring feeding behaviour of cows in a grazing environment, even though it was originally developed for cows in indoor feeding systems. The accuracy of 1-min summaries and 1-h summaries was very high with kappa-values between 0.85 and 0.89 and CCC-values ranging from 0.92 to 0.99, respectively. The noseband sensor tended to overestimate grazing time and grazing bites slightly, whereas the detection of rumination time was very accurate. The accuracy between observer and automated measurement was moderate for detecting rumination chews due to issues regarding plausibility checks for the specific experimental periods. The validation of the newly implemented parameters in the RumiWatch Converter V.0.7.3.36 for grazing and rumination bouts delivered moderate or high concordance. The pedometer showed very promising results with CCC-values ranging from 0.92 to 1.00. Its performance in detecting walking was slightly weaker than in detecting standing and lying, but still appropriate for a measurement system. Based on those results, it may be concluded that the RumiWatchSystem is a reliable sensor technology to monitor grazing behaviour and thus, is a useful tool for research purposes in a grazing environment.

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