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Brief Report

Validation and Use of the RumiWatch Noseband Sensor for Monitoring Grazing Behaviours of Lactating Dairy Cows

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Abstract: Precision livestock farming (PLF) supports the development of sustainable dairy production. The sensors used in PLF provide valuable information for farm management, but they must be validated to ensure the accuracy. The goal of this study was to validate and use the RumiWatch sensor (RWS; Itin+Hoch GmbH, Liestal, Switzerland) to differentiate prehension bites, eating chews, mastication chews and rumination chews in pressure-based system. Twenty cows were used for 14 days to provide a validation dataset. The concordance correlation coefficient (CCC) was adopted to test the concordance between the RumiWatch sensor and video observation. The RumiWatch sensor performed well in counting prehension bites (CCC = 0.98), eating chews (CCC = 0.95) and rumination chews (CCC = 0.96), while it showed an acceptable concordance in counting mastication chews with video observation (CCC = 0.77). Moderate correlations were found between eating chews and daily milk production: daily milk production (kg/day) = 0.001151 × eating chews (chews/day) − 11.73 (R^2 = 0.31; standard error (SE) = 8.88; p = 0.011), and between mastication chews and daily milk production: daily milk production (kg/day) = 0.001935 × mastication chews (chews/day) + 2.103 (R^2 = 0.34; SE = 8.70; p = 0.007). Overall, the results indicated that the RumiWatch sensor can be confidently used to quantify and differentiate prehension bites, eating chews and rumination chews; in addition, ingestive behaviours explained up to 34% of the variation in milk production.

Keywords: sensor; automatic milking; eating behaviour; milk production; precision agriculture

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Citation: Li, Z.; Cheng, L.; Cullen, B. Validation and Use of the RumiWatch Noseband Sensor for Monitoring Grazing Behaviours of Lactating Dairy Cows. *Dairy* **2021**, *2*, 104–111. https://doi.org/10.3390/dairy2010010

Received: 7 December 2020
Accepted: 26 January 2021
Published: 10 February 2021

1. Introduction

In the precision dairy production system, observation of ingestive and rumination behaviours of dairy cows can assist in detecting disease, evaluating animal performance, estimating individual grazing intake and assessing animal welfare [1,2]. It can also guide farms to achieve better management in pasture allowance and animal production [3]. Precision management is reliant on the improved understanding of grazing intake at the level of individual cow [4]. Over the past two decades, several automatic sensors have been designed to monitor grazing behaviours without intensive labour inputs and human interference [5]. The RumiWatch system (RWS; Itin+Hoch GmbH, Liestal, Switzerland) is a jaw movements sensor, which can monitor the prehension bites, mastication chews, eating chews and rumination chews. Previous pressure-based sensors, such as ART-MSR Rumination sensor (MSR Electronic, Henggart, Switzerland) and the IGER Behaviour Recorder (Ultra Sound Advice, London, UK), are complex to use, can only record cow behaviours for several days, and involve a labour-intensive process to perform analysis of the raw data [5]. In contrast, the RumiWatch sensor can record cow behaviours up to four months, and the RumiWatch Converter has an integrated algorithm to classify the jaw movements by using the raw data [6]. Previous studies have evaluated the concordance of the RumiWatch sensor in both grazing and indoor feeding systems [2,6–9]. However, previous studies have not validated mastication chews in dairy cows, despite mastication chew being a major indicator of bite mass and pasture quality [2,7]. Therefore, the first objective of this study was to validate the use of the RumiWatch noseband sensor in pasture grazing condition with cows managed under automatic milking system and voluntary cow movement.

There was a positive correlation found between ingestive behaviours and grazing intake [10], while it is also known that grazing intake is a major contributor to the daily milk production [11]. Thus, the second objective of this study was to investigate the potential relationships between daily milk production and ingestive and rumination behaviours, in pasture-based automatic milking system with voluntary cow movement.

2. Materials and Methods

2.1. Site and Background Information

All animal handling procedures were approved by the Animal Ethics committee (ID number: 2015150.1) at The University of Melbourne. The study was conducted during 22nd September–6th October 2020 at The University of Melbourne Dookie Campus automatic milking (robotic) dairy farm, Northern Victoria, Australia (36°22′48″ S, 145°42′36″ E). The robotic dairy farm contains three Lely Astronaut T4C robotic milking machines (Lely Industries NV, Maasland, The Netherlands) with a capacity to milk up to 180 cows per day in total. Cows were trained to use the robotic dairy system and were milked up to three times daily. The robotic milking system automatically record production parameters: lactation days, milking frequency per day, number of lactations, liveweight (kg), milk production (kg/day), milk fat and protein content (%), concentrate feed intake (kg/day). The experimental cows (n = 20) grazed on ryegrass dominant pasture with other non-experimental cows (n = 136) in the herd. They were managed under a three-way grazing system (i.e., A-B-C grazing) per 24 h (approximately 8 h in each grazing paddock), with voluntary movement allowed to access to paddock and milking robots [12]. The cows' diet consisted of 16.0 kg DM/cow/day ryegrass-based pasture, 7.6 kg DM/cow/day concentrate feed and 1.0 kg DM/cow/day grass straw. Climate data from the Dookie Agricultural College weather station [13] showed that in the experimental period the average maximum temperature was 18.5 °C (range 12.3–30.7 °C), minimum temperature was 6.5 °C (range 0.4–14.0 °C) and there was a total of 19 mm rainfall with rain falling in two main events of 6 mm each on 25th September and 1st October 2020. Daily solar radiation ranged from 7.2–22.8 MJ/m^2.

2.2. Animals

A total of 10 primiparous (parity = 1; body weight = 577.50 ± 56.76 kg; days in milk = 53.40 ± 15.09 days; milk production= 23.38 ± 5.53 kg/day) and 10 multiparous (parity = 2.1; body weight = 584.60 ± 57.18 kg; days in milk = 29.70 ± 3.77 days; milk production = 39.84 ± 6.91 kg/day) lactating Holstein cows were selected to conduct the study. Each cow wore the RumiWatch noseband sensor for 14 days, which consisted of a 2-day adaptation and 12-day recording period. Sensors were time synchronised and activated by the RumiWatchManager software (RumiWatchManager 2; Itin+Hoch GmbH, Liestal, Switzerland) and the wireless signal device (ANT+, Itin+Hoch GmbH, Liestal, Switzerland).

2.3. Behaviour Observations

During each observation, one cow was observed at a continuous 10-min interval (i.e., sequence). A total of 73 sequences of valid video observation were recorded. Some cows may be observed multiple times during a day so that a range of ingestive and rumination behaviours can be recorded. A tripod phone holder (Inca i3642B tripod; Inca; Altona North; Australia) and a time-synchronised iPhone SE2 (iPhone SE2; Apple; Cupertino, CA, USA) were used to record the cow behaviours during the observation times. The behaviours were counted by reviewing the video recordings after all recording finished.

2.4. RumiWatch

The RumiWatch sensor consisted of a noseband pressure sensor in addition to a 3-axis accelerometer and an integrated data logger. The noseband pressure sensor is made up of a vegetable oil-filled silicone tube with a built-in pressure sensor placed in the casing of a halter over the bridge of the cow's nose. The curvature of the noseband is altered by the cow's jaw movement, causing a pressure change in the silicone tube. The silicone tube passes the pressure to the pressure sensor. The data logger registers the pressure in the noseband sensor at a constant logging rate of 10 Hz and saves the raw data to an SD Memory Card. The sensor allows individual jaw movement to be recorded. All the sensors were time-synchronised with the laptop and iPhone before the recording start.

2.5. Data Preparation

Data loggers recorded the raw data of 20 cows' behaviours. Then, the raw data from the RumiWatch sensor was downloaded to the computer via an USB. The raw data during the experimental periods were inputted into the RumiWatch Converter (RumiWatch Converter version V 0.7.4.13; Itin + Hoch GmbH, Liestal, Switzerland) and converted into the behaviour counts (prehension bites, eating up, eating down, and rumination chews). These values were automatically grouped into 10-min periods by the RumiWatch Converter, eating chews were calculated from the equation: eating chews = eating up + eating down, and the mastication chews were calculated as: mastication chews = eating chews − prehension bites. The observation data were obtained by counting all the video recordings, and there were 730 min of valid observations. Then, the converted data outputs from the RumiWatch Converter were coupled with the observation data in the same periods. In addition, daily milk production records for individual cows were collected from the Lely T4C robotic milking system and used to establish relationship with behaviours data. To reduce the lag effect of milk production from pasture ingestion, the 12-day behaviour counts and daily milk production data were averaged to establish the relationships between behaviours and daily milk production (Supplementary Materials).

2.6. Statistical Analyses

Statistical analysis was performed by using Genstat 18th Edition (Genstat 18th Edition, VSN International, Hemel Hempstead, UK). The following analyses were conducted to evaluate the correlation between the RumiWatch system (RWS) and video observations (VO).

Concordance correlation coefficient (CCC) was performed between RWS data (prehension bites, mastication chews, eating chews, rumination chews) and VO data. As VO is the reference method, thus, the higher concordance between two methods means higher accuracy of RWS. The CCC was classified as: 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 [14]. Moreover, the Pearson correlation (i.e., r) was conducted between behaviour data and milk production. Strength of association was classified as: weak = 0.1 to 0.3 or −0.1 to −0.3, medium = 0.3 to 0.5 or −0.3 to −0.5, strong = 0.5 to 1.0 or −0.5 to −1.0 [14]. Further, R-squared (i.e., R^2) was also reported from both CCC and Pearson correlation analysis.

3. Results

3.1. Validation of the RumiWatch Sensor

The evaluation of grazing jaw movements was based on 73 sequences measured by video observation and by the RumiWatch sensor. Prehension bites while grazing was observed for a mean of 425 bites in 10-min intervals (42.5 bites/min). In contrast, the RumiWatch sensors detected the number of prehension bites with a mean of 433 bites in the same period (the average rate of prehension bites = 43.3 bites/min) (Table 1). The mean difference between two methods was 8 bites/10-min interval. The correlation of prehension bites had an CCC = 0.98 ($p < 0.001$).

Table 1. Concordance correlation coefficient (CCC) and correlation coefficient (r) results of each behaviour identified by RumiWatch sensor (RWS) compared with the video observation (VO).

Behaviour	*n* (10-min Interval)	RWS (10-min Interval)	VO (10-min Interval)	Bias [1]	*r*	CCC	C_b [2]	Lower (95% CI)	Upper (95% CI)	*p* [3]
Prehension bites	54	433	425	8	0.98	0.98	1.00	0.96	0.99	<0.001
Eating chews	57	638	603	35	0.96	0.95	0.99	0.92	0.97	<0.001
Mastication chews	57	220	193	27	0.81	0.77	0.96	0.65	0.86	<0.001
Rumination chews	28	475	494	−19	0.97	0.96	1.00	0.93	0.98	<0.001

[1] Bias show the fixed effect of the sensor method compared with the reference method (video observation); it may be interpreted the systematic error of the sensor method; [2] C_b = Bias Correction Factor, Ideal = 1, lower values indicate bias from the 1:1 line; [3] *p* = *p*-value related to association between changes of RWS and changes of VO.

On average, 603 eating chews were counted per 10-min interval by video observation, while 638 eating chews per 10-min interval (the average rate of eating chews = 63.8 chews/minute) were measured by noseband sensors. The difference between the methods was 35 chews/10-min interval (as Table 1 shown). The correlation of CCC = 0.95 ($p < 0.001$). The average rate of mastication chews visually was counted as 19.3 chews/minute (193 chews/10-min interval), whereas RumiWatch sensor had a rate of 22.0 chews/minute (220 chews/10-min interval) in counting mastication chews. The correlation was CCC = 0.77 ($p < 0.001$) for mastication chews measured by two methods.

The comparison of rumination chews counted by both video observations and RumiWatch sensor is presented in Table 1 and Figure 1. The RumiWatch sensor recorded a range of counts from 14 to 720 chews in one 10-min interval, with a mean of 475 chews/10-min interval (the average rate of rumination chew = 47.5 chews/min). Meanwhile, the video observation recorded a range between 162 and 719 chews in one 10-min interval with a mean of 494 chews/10-min interval (49.4 chews/min). The difference of the means was 19 chews per 10-min interval (1.9 chews/min). The correlation of rumination chews had an CCC = 0.96 ($p < 0.001$).

3.2. The Relationship between Sensor Behaviour Data and Milk Production

The correlation between ingestive and rumination behaviours per cow (including grazing bites, eating chews, mastication chews and rumination chews) and daily milk production per cow are listed in Table 2. There were no correlations between prehension bites, rumination chews and daily milk production during the experimental period. However, there were moderate correlations found between the eating chews, mastication chews and daily milk production:

Table 2. Correlation analysis of cow's average behaviours identified by RumiWatch sensor (RWS) compared with the average daily milk production (DMP) over a 12-day experimental period.

Behaviour	RWS (chews/day)	DMP (kg/day)	R^2	*r*	SE [1]	*p* [2]
Prehension bites	22407.4	31.6	0.07	0.27	10.31	0.258
Eating chews	37655.2	31.6	0.31	0.56	8.88	0.011
Mastication chews	15247.8	31.6	0.34	0.58	8.70	0.007
Rumination chews	29837.4	31.6	0.03	0.18	10.52	0.458

[1] SE = standard error; [2] *p* = *p*-value related to association between changes of RWS and changes of DMP.

Daily milk production (kg/day) = 0.001151 × eating chews (chews/day) − 11.73 (R^2 = 0.31; SE = 8.88; p = 0.011).

Daily milk production (kg/day) = 0.001935 × mastication chews (chews/day) + 2.103 (R^2 = 0.34; SE = 8.70; p = 0.007).

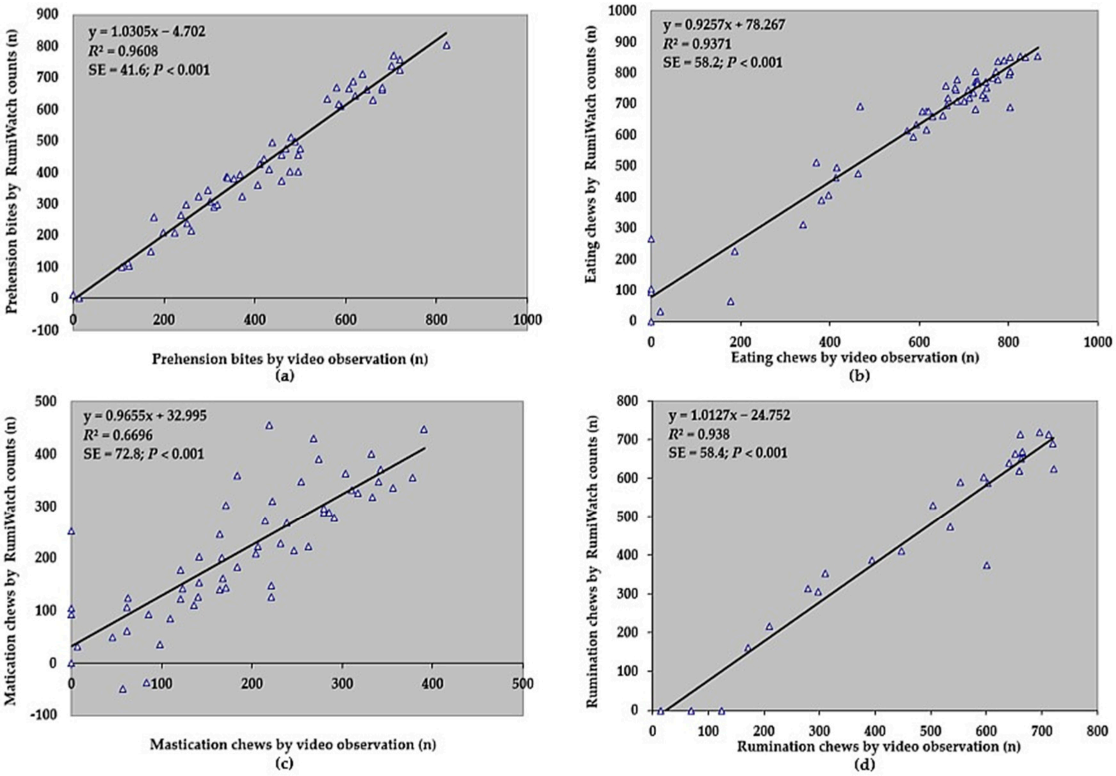

Figure 1. The correlation between video observations from video recordings and automatic measurements with the RumiWatch sensor for the number of prehension bites (**a**), eating chews (**b**), mastication chews (**c**) and rumination chews (**d**). The prediction equation of the number of prehension bites from the RumiWatch sensor is prehension bites RumiWatch (bites) = 1.0305 × prehension bites video observation (bites) − 4.702 (SE = 41.6; $p < 0.001$); prediction equation of the number of eating chews from the RumiWatch sensor is eating chews RumiWatch (chews) = 0.9257 × eating chews video observation (chews) + 78.267 (SE = 58.2; $p < 0.001$); prediction equation of the number of mastication chews from the RumiWatch sensor is mastication chews RumiWatch (chews) = 0.9655 × mastication chews video observation (chews) + 32.995 (SE = 72.8; $p < 0.001$); Prediction equation of the number of Rumination chews from the RumiWatch sensor is rumination chews RumiWatch (chews) = 1.0127 × rumination chews video observation (chews) − 24.752 (SE = 58.4; $p < 0.001$).

4. Discussion

4.1. Validation of the RumiWatch Noseband Sensor

The RumiWatch noseband sensor had very high accuracies in measuring the prehension bites (CCC = 0.98), eating chews (CCC = 0.95), and rumination chews (CCC = 0.96). The accuracies of prehension bites and rumination chews in this study (RumiWatch Converter V.0.7.4.13) were generally higher than the previous study by using an earlier version of RumiWatch Converter V. 0.7.3.36 (CCC = 0.78 for prehension bites and CCC = 0.94 for rumination chews) in a pasture-based system [2]. This may be caused by the improvement of the algorithm (RumiWatch Converter V.0.7.4.13 is the latest version), which improved the classification of different jaw movements. However, the concordance of the mastication chews was lower than other jaw movements (CCC = 0.77) in this study. This may be due to the sensors not directly counting the mastication chews. The mastication chews were calculated as: eating chews—prehension bites, which may have accumulated the counting errors from eating chews and prehension bites by the RumiWatch sensor.

The RumiWatch sensor slightly overestimated the number of prehension bites (1.9%), eating chews (5.8%) and mastication chews (14.0%), whereas the sensor slightly underestimated the number of rumination chews (3.8%), compared with video observation. This finding is similar with a previous study [7]. Video observation may miss some counts with quick bites or a blocked view. The previous study has indicated that the detection of grazing bites by the automatic system may be more precise than visual observation [15].

However, the underestimation of rumination chews may be due to some rumination chews having less pressure caused or misclassified by the sensors as eating chews, particularly, when the rumination chews combined with some postures, such as rumination with the head moving or licking. Overall, the RumiWatch had a high accuracy in quantifying prehension bites, eating chews and rumination chews.

4.2. Ingestive and Rumination Behaviour and Milk Production Relationships

On average there were 43.3 prehension bites per minute, 63.8 eating chews per minute and 47.5 rumination chews from this study, which is in agreement with previous reports [16,17]. These correlations between ingestive behaviours and milk production over a 12-day experimental period were explored. The results showed that there were moderate associations between eating chews and daily milk production (R^2 = 0.31; SE = 8.88; p = 0.011) as well as mastication chews and daily milk production (R^2 = 0.34; SE = 8.70; p = 0.007). This finding is novel, as to the best of our knowledge, there was no previous study directly demonstrated these associations. Such associations may well be related to the inter-relationships among ingestive behaviours, DMI and milk production. It is well known that there is a positive correlation (R^2 = ~0.8) between ingestive behaviours and intake [18], and also a positive relationship (R^2 = ~0.5) between intake and daily milk production [11]. Therefore, it is not surprising that ingestive behaviours measured in this study were positively related to milk production. However, it is important to note that approximately 70% of the variation in milk production was not explained by ingestive behaviours in this study. This may be due to different milk production efficiencies (e.g., feed conversion efficiency) during the different lactation periods. For instance, cows usually mobilise their body condition for lactation in the early lactation period to support milk production, which lead to a decreased in body weight and increased milk production efficiency [19]. However, after reaching the peak of lactation, the cow reduces its milk production efficiency in mid-lactation and late lactation with the regaining of body weight [19]. Additionally, the environmental conditions can affect the predictions of daily milk production based on ingestive behaviours. For instance, the changes of illumination time, temperature, weather, pasture distribution [20] has not been involved as factors in this study. Besides, in automatic milking system, pasture accessibility and quality may affect milk production [21]. Compared with cows late in milking order, cows early in milking orders have early access to the new paddock, where the pasture generally has higher mass and nutritive value [22]. This can result in the late cows may spend more time on grazing and perform more bites to compensate for the low dry matter intake [12]. Therefore, it is possible that the late cows performed a high number of ingestive behaviours but with low dry matter intake and low nutrient intake, which finally leads to a low milk production. Future research is needed to use a larger dataset to understand the impact of milking order on intake and milk production under a pasture-based automatic milking system with voluntary cow movement.

5. Conclusions

The RumiWatch noseband sensor is a useful device to monitor the jaw movements in prehension bites, eating chews and rumination chews in pasture-based automatic milking system with voluntary cow movement. Meanwhile, it also performed an acceptable result with little random and systematic error in measuring the mastication chews. This study also indicated that the new algorithm (RumiWatch Converter version V 0.7.4.13) has high accuracy in classifying and identifying different ingestive and rumination behaviours.

There are medium associations has been found between eating chews, mastication chews and daily milk production. However, due to low accuracy in measuring mastication chews by sensor, the prediction of milk production based on mastication chews is not recommended to use under the current accuracy. In addition, due to the limitations of the experimental conditions, some factors, such as days in milk, body weight, milking orders and environmental conditions, have not to be included in the predictions. Therefore, the future study needs to consider the impacts of multiple factors on both ingestive and rumination behaviour and daily milk production.

Supplementary Materials: The following are available online at https://www.mdpi.com/2624-862X/2/1/10/s1.

Author Contributions: Conceptualization, B.C. and L.C.; Methodology, B.C., L.C. and Z.L.; Validation, Z.L.; Formal Analysis, Z.L.; Investigation, Z.L.; Resources, B.C.; Data Curation, B.C., L.C. and Z.L.; Writing—Original Draft Preparation, Z.L.; Writing—Review and Editing, L.C. and B.C.; Visualization, Z.L.; Supervision, B.C. and L.C.; Project Administration, B.C.; Funding Acquisition, B.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by Animal Ethics committee (ID number: 2015150.1) on 20 May 2020 at The University of Melbourne.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available in Supplementary Material here.

Acknowledgments: We would like to express appreciation to Pablo S Alvarez from AgriVictora, Ellinbank for providing statistical advice. We would also like to extend our gratitude to Nathan Anderson and Jess Reeks from Dookie dairy farm, The University of Melbourne for their help in conducting this study.

Conflicts of Interest: The authors declare no conflict of interest.

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