agriculture

MDPI

Article

Utilizing Noseband Sensor Technology to Evaluate Rumination Time as a Predictor of Feeding and Locomotion Behaviors in Dairy Cows

Ramūnas Antanaitis [1,*], Karina Džermeikaitė [1], Justina Krištolaitytė [1], Samanta Arlauskaitė [1], Akvilė Girdauskaitė [1], Kotryna Tolkačiovaitė [1], Renalda Juodžentytė [2], Giedrius Palubinskas [2], Aistė Labokojytė [1], Greta Šertvytytė [1], Gabija Lembovičiūtė [1] and Walter Baumgartner [3]

1 Large Animal Clinic, Veterinary Academy, Lithuanian University of Health Sciences, Tilžės Str. 18, LT-47181 Kaunas, Lithuania; karina.dzermeikaite@lsmu.lt (K.D.); justina.kristolaityte@lsmu.lt (J.K.); samanta.arlauskaite@lsmu.lt (S.A.); akvile.girdauskaite@lsmu.lt (A.G.); kotryna.tolkaciovaite@stud.lsmu.lt (K.T.); aiste.labokojyte@stud.lsmu.lt (A.L.); greta.sertvytyte@lsmu.lt (G.Š.); gabija.lemboviciute@lsmu.lt (G.L.)

2 Department of Animal Breeding, Veterinary Academy, Lithuanian University of Health Sciences, Tilžės Str. 18, LT-47181 Kaunas, Lithuania; renalda.juodzentyte@lsmu.lt (R.J.); giedrius.palubinskas@lsmu.lt (G.P.)

3 Clinical Centre for Ruminant and Camelid Medicine, University of Veterinary Medicine, Veterinaerplatz 1, A-1210 Vienna, Austria; walter.baumgartner@vetmeduni.ac.at

* Correspondence: ramunas.antanaitis@lsmuni.lt; Tel.: +370-67349064

Abstract: The objective of the study was to examine the relationship between rumination time and various parameters related to eating and locomotion, including other chews, eating chews, eating time, drinking gulps, bolus counts, chews per minute, activity, and activity change, utilizing RumiWatch technology. The RumiWatch noseband sensor (RWS; ITIN + HOCH GmbH, Feeding Technology, Liestal, Switzerland) was utilized to record time and frequency related to rumination, eating, and movement behaviors. The RumiWatch system (RWS) was put into operation from 1 June 2023 to 30 June 2023. The first two weeks, from 1 June to 14 June 2023 at 7 a.m., served as a period for the cows to acclimate to the RWS, acting as an adjustment phase. Monitoring activities with the RWS commenced on 7 a.m. and lasted until the end of the month, 30 June 2023, with data being recorded daily on an hourly basis. Our findings indicate a significant negative correlation between rumination time and other activity time ($r = -0.50$), which represents the duration cows allocate to behaviors outside of eating, chewing cud, or distinct movement activities. Additionally, a significant negative correlation was observed between rumination time and eating time ($r = -0.54$). Furthermore, we observed strong positive correlations with rumination chews ($r = 0.84$) and bolus ($r = 0.75$). A weaker positive correlation was found with chews per minute ($r = 0.29$), while no significant correlation was detected with drinking gulps ($r = 0.10$). Based on our findings, we recommend the implementation of the RumiWatch System for monitoring rumination and feeding behaviors in lactating dairy cattle. This technology provides valuable insights into cow health and welfare, enabling early detection of potential health issues and improving herd management practices.

Keywords: innovations; dairy cows; feeding; locomotion behavior; rumination

Academic Editor: Maciej Zaborowicz

Received: 29 November 2024
Revised: 23 January 2025
Accepted: 28 January 2025
Published: 29 January 2025

Citation: Antanaitis, R.; Džermeikaitė, K.; Krištolaitytė, J.; Arlauskaitė, S.; Girdauskaitė, A.; Tolkačiovaitė, K.; Juodžentytė, R.; Palubinskas, G.; Labokojytė, A.; Šertvytytė, G.; et al. Utilizing Noseband Sensor Technology to Evaluate Rumination Time as a Predictor of Feeding and Locomotion Behaviors in Dairy Cows. *Agriculture* **2025**, *15*, 296. https://doi.org/10.3390/agriculture15030296

1. Introduction

Precision livestock farming (PLF) involves using real-time monitoring technologies to manage the smallest production units, focusing on individual animals via sensor technology.

PLF presents substantial possibilities for creating value among different stakeholders, chiefly acting as a powerful tool for farmers [1]. Precision livestock farming makes a substantial contribution to increases in productivity. Farmers can improve breeding and feeding practices, which will improve milk production and reproductive outcomes by utilizing technologies that track the performance of individual animals. This technology can offer evidence-based evaluations of animal welfare, which can be crucial in enhancing farm management techniques and production, according to the systematic review [1]. It improves the ability to enhance animal welfare, efficiency, and health, and simultaneously minimizes environmental footprints [2]. Sensor data can be utilized either on its own or together with traditional health monitoring methods to identify cows with health issues [3]. By tracking behavioral and health indicators, it is possible to recognize minor changes before the manifestation of clear clinical signs. Data collected before a diagnosis is often more critical for early detection and intervention, as it may predict risk or identify disease more efficiently than clinical observation alone [4]. Nonetheless, further research is required to establish guidelines for disease identification and prevention using data from automated health monitoring systems [5]. Diseases occurring post-calving, like metritis, ketosis, mastitis, and others, can impact an animal's walking behavior, making early detection vital to mitigate the adverse effects of mastitis [6]. In diagnosing such conditions, rumination sensors have been effective in identifying mastitis, subclinical ketosis, acidosis, and other diseases in their initial stages [7].

The RumiWatch noseband sensor (RWS) has undergone testing in dairy herds globally for both confinement and grazing situations, suggesting its potential as a benchmark for validating other animal behavior monitoring technologies [8]. Pereira et al. explored algorithms for feeding and rumination behavior, finding that a neck-mounted accelerometer was more accurate than the RWS [8]. They also used the RWS to assess the Smartbow ear tag sensor in grazing herds in Minnesota and Ireland, demonstrating strong correlations between grazing behavior and visual assessments [8]. The noseband sensor in the RWS is specially designed and validated as an automated tool for identifying rumination and feeding behaviors in stable-housed dairy cows [9]. Although the RWS is capable of forecasting feed intake and aiding in the management of grazing, it comes at a higher cost compared to other precision agriculture technologies and necessitates daily upkeep [9]. This noseband sensor, thoroughly developed and tested, is acknowledged as a dependable instrument for automatically monitoring feeding and movement patterns in dairy cows [9].

The RumiWatch System effectively identifies prehension bites in both grazing and stall-fed cows, with both converters showing superior accuracy in detecting ingestive behaviors in grazing cows compared to stall-fed cows [10]. The observation of rumination time, either independently or in conjunction with other variables, has been identified as a method for diagnosing illnesses in dairy cattle, showing a strong correlation with both subclinical and clinical health issues [11]. Monitoring the rumination and feeding behaviors of dairy cows automatically has the potential to identify health issues early. Additionally, observing both behaviors together could enhance the accuracy of detecting problems.

Precision livestock farming systems are utilized to create alerts for health and estrus, and are particularly adept at measuring behavioral shifts surrounding the calving process, with techniques such as monitoring rumination and feeding times showing promise for detecting cows nearing calving. Furthermore, a lot of research has been done on the time of rumination in connection to calving. There was a notable drop in rumination activity in the hours preceding calving, and this decline continued for a few hours after giving birth. This implies that rumination behavior is influenced by physiological factors like the calving process in addition to being a reaction to feeding [10]. Thus, the RumiWatch system can be quite helpful in keeping an eye on these developments and enabling prompt actions as needed [12]. Given the strong correlation between rumination and digestive health and general well-being, this is essential for maximizing animal welfare and production. For example, longer periods of rumination are frequently linked to greater nutritional absorption and digestion, which can result in higher milk production [10].

According to our previous studies, the RWS specifies these data, offering parameters that distinctly vary from others, and in this past research, we suggested additional studies on physiological norms using a broader sample of clinically healthy cows [13]. Automated tracking of rumination and feeding activities in dairy cows appears to be a promising method for identifying health issues, and integrating these behaviors could improve detection rates, with monitoring rumination behavior on an individual basis being simpler and more practical than tracking each cow's feed consumption, making it a feasible option for adoption on commercial farms [14].

The aim of the current study was to assess rumination time recorded using innovative technologies as a parameter for evaluating feeding and locomotion behaviors by measuring eating chews, chewing rate (chews per minute), eating time, rumination time, rumination chews, drinking gulps, bolus activity, and general activity in dairy cows.

2. Materials and Methods

2.1. Study Animal Housing Conditions

In this study, we complied with the Lithuanian Law on Animal Welfare and Protection, obtaining authorization with the approval number PK012858. The research was conducted in West Lithuania (coordinates: 55.819156, 23.773541) from 1 June 2023 to 30 June 2023. The dairy cows were housed in free-stall barns equipped with natural and mechanical ventilation systems, featuring sidewall openings and circulation fans. They were fed a total mixed ration (TMR) formulated to meet their physiological requirements year-round. The average temperature during this period was 23 degrees Celsius. Feedings were provided daily at 06:00 and 18:00, offering a total mixed ration (TMR) specifically formulated for high-yielding, multiparous cows. This diet was designed to meet or exceed the nutritional requirements of a 500 kg Holstein cow producing 37 kg of milk per day. The TMR composition is detailed in Tables 1 and 2. Milking was conducted twice daily, at 05:00 and 17:00, using a DeLaval milking parlor system (DeLaval Inc., Tumba, Sweden). Out of 1160 clinically assessed Holstein breed cows, 434 were selected for the study, specifically those in their second or subsequent lactation and between 5 to 30 days post-calving. The average weight of these cows was 550 kg ± 45 kg, with an average energy-corrected milk production (with 4.2% fat and 3.6% protein) of 12,500 kg per cow per lactation.

Table 1. Composition of TMR.

TMR Component	Value
Corn silage	25%
Alfalfa grass hay	5%
Grass silage	20%
Sugar beet pulp silage	15%
Grain concentrate mash	30%
Mineral mix	5%

2.2. Registration of Parameters

2.2.1. Registration of Rumination, Eating, and Locomotion Behavior

The RumiWatch noseband sensor (RWS; ITIN + HOCH GmbH, Feeding Technology, Liestal, Switzerland) was utilized to record biomarkers related to rumination, eating, and movement behaviors. The RumiWatch features a halter with a fluid-filled pressure tube and an integrated pressure sensor (Figure 1).

Table 2. Chemical composition of TMR.

TMR Component	Value
Dry Matter (DM)	48.8%
Neutral Detergent Fiber (NDF)	28.2% of DM
Acid Detergent Fiber (ADF)	19.8% of DM
Non-Fiber Carbohydrates (NFC)	38.7% of DM
Crude Protein (CP)	15.8% of DM
Net Lactation Energy	1.6 Mcal/kg

Figure 1. Cow with RumiWatch noseband sensor (front and side view) (RWS; ITIN + HOCH GmbH, Feeding Technology, Liestal, Switzerland.

This sensor transmits pressure signals to a data logger attached to the halter, encased in a sturdy plastic housing. The device also includes a memory card slot and an accelerometer that tracks three-dimensional head movements. Data from both the acceleration and pressure sensors are recorded in binary format at a frequency of 10 Hz. The RumiWatch setup is equipped with a wireless data transmission unit connected to the halter, enabling the immediate gathering of data. The RWC software (Version 2.2.0.0) uses advanced algorithms to precisely interpret the behavioral data derived from the 10 Hz pressure signals over different time frames (Table 3). The RWS is designed to be lightweight and non-invasive, and cows typically adapt to it quickly without showing signs of discomfort or attempts to remove or damage the system.

2.2.2. Duration of Parameter Registration

The RumiWatch system (RWS) was put into operation from 1 June 2023 to 30 June 2023. The first two weeks, from 1 June to 14 June 2023, served as a period for the cows to acclimate to the RWS, acting as an adjustment phase. Monitoring activities with the RWS commenced on 14 June 2023 and lasted until the end of the month, 30 June 2023, with data being recorded daily on an hourly basis. During the acclimation phase from 1 June to 14 June 2023, the BROLIS HerdLine in-line milk analyzer was operational at each milking session, continuously measuring the milk composition of each cow throughout the process.

2.3. Statistical Analysis

To analyze the relationships between key variables, regression analyses were performed. Both linear and nonlinear models (polynomial and logarithmic) were evaluated to identify the best fit for each relationship. Model selection was based on the following criteria: determination coefficients (R^2) to assess the goodness of fit; residual analysis to ensure the appropriateness of the model; and visual inspection of the data trends to confirm the nature of the relationships.

The normality of all variables was tested using the Shapiro–Wilk test. Results indicated that none of the variables followed a normal distribution ($p < 0.05$).

Confidence intervals were calculated for the regression models to enhance interpretability, and both regression equations and determination coefficients are reported in the Section 3. Statistical analyses were conducted using IBM SPSS Statistics for Windows, Version 25.0, and Python 3.10 (pandas, sklearn, and scipy libraries). All statistical tests were performed at a significance level of $p < 0.05$.

Table 3. Overview of the parameters under investigation.

Investigated Parameter	Overview
Eating chews (EC) (n/h)	Total number of chews and bites made during eating.
Chews per minute (CPM) (n/min)	Chewing movements occurring during rumination per minute
Eating time (ET) (min/h)	The total time of swallows throughout the act of eating.
Rumination time (RT) (min/h)	Time spent bolus swallowing, chewing or ruminating, and regurgitation, including 5 s intervals.
Rumination chews (RC)	Mastication during rumination to physically reduce regurgitated content into finer particles using the mouth.
Drinking gulps (DG) (n/h)	The total count of swallows throughout the drinking activity.
Bolus (B) (n/h)	The total number of sips or swallows taken while drinking.
Activity (A) (min/h)	The cumulative duration of walking within a given recording period, measured in minutes.
Other activity time (OAT)	The duration cows allocate to behaviors outside of eating, chewing cud, or distinct movement activities.

3. Results

In this study, we investigated rumination time recorded using innovative technologies as a parameter for evaluating feeding and locomotion behaviors. The analysis included measurements of eating chews, chewing rate (chews per minute), eating time, rumination time, rumination chews, drinking gulps, bolus activity, and overall activity in dairy cows (Table 4).

Table 4. Descriptive statistics of the investigated traits.

Statistic	Eating Chews	Chews Per Minute	Eating Time	Rumination Time	Rumination Chews	Drinking Gulps	Bolus	Activity	Other Activity Time
Sample Size	2415.00	2415.00	2415.00	2415.00	2415.00	2415.00	2415.00	2415.00	2415.00
Mean	379.35	51.53	4.74	17.51	1129.85	183.65	19.46	63.96	31.19
Standard Deviation	671.83	34.13	7.98	15.78	1051.67	351.22	17.63	51.39	16.48
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25th Percentile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	32.00	18.80
Median	17.00	70.59	0.27	16.53	1012.00	5.00	19.00	56.00	28.53
75th Percentile	507.00	76.19	6.67	29.33	1917.50	211.50	32.00	88.00	41.33
Maximum	4064.00	87.27	51.47	60.00	4090.00	2593.00	88.00	408.00	60.00

Zero values indicate the absence of the recorded behavior during the observation period.

Our results revealed significant relationships between rumination time and various eating and locomotion parameters recorded by innovative technologies. Notably, strong positive correlations were observed with rumination chews (r = 0.84, $p < 0.001$)) and bolus (r = 0.75, $p < 0.001$), while significant negative associations were found with eating time (r = −0.54, $p < 0.001$)) and other activity time (r = −0.50, $p < 0.001$). Weaker correlations were observed for chews per minute (r = 0.29, $p = 0.023$)) and activity (r = −0.34, $p = 0.015$), whereas the relationship with drinking gulps was not significant (r = 0.10, $p = 0.412$) (Table 5).

Table 5. Correlation coefficients between rumination time and other investigated traits.

Variable Pair	Spearman *r*	Spearman *p* Value
Other activity time	−0.65	<0.001
Eating Chews	−0.48	<0.001
Chews Per Minute	0.29	<0.05
Eating Time	−0.54	<0.001
Rumination Chews	0.84	<0.001
Drinking Gulps	0.10	>0.05
Bolus	0.75	<0.001
Activity	−0.34	<0.05

3.1. The Relationship Between Rumination Time and Other Activity Time

The analysis of the relationship between rumination time (RT) and other activity time (OAT) revealed a significant inverse association. Spearman's correlation coefficient confirmed the association (r = −0.65, $p < 0.001$). As RT increases, OAT decreases (Figure 2).

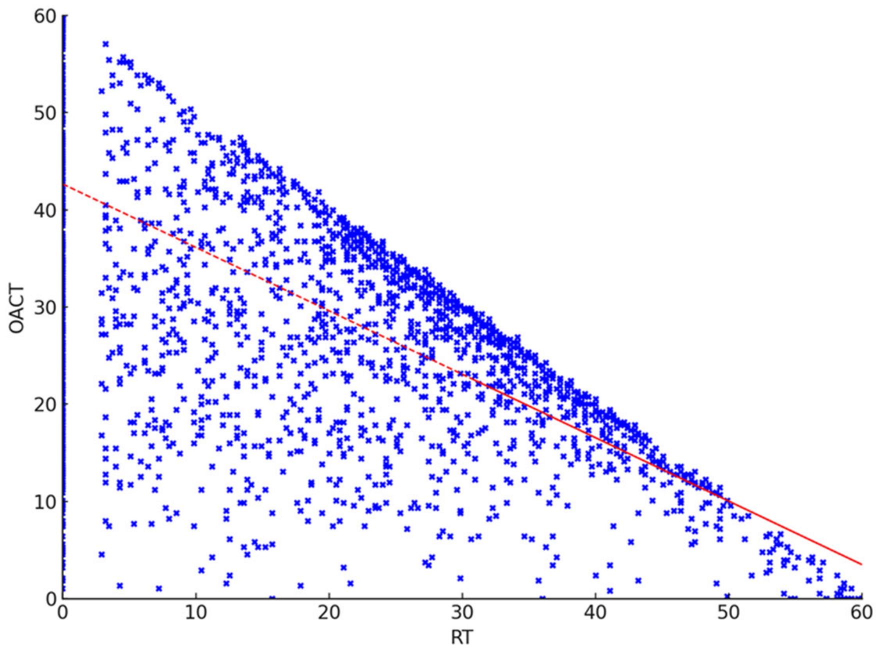

Figure 2. The relationship between Rumination time (RT) and Other activity time (OAT). r = 0.78.

3.2. The Relationship Between Rumination Time and Eating Time

We found a negative association between rumination time (RT) and eating time (ET). Spearman's correlation coefficient supported this finding (r = −0.54, $p < 0.001$). This result highlights a diminishing impact of increased RT on ET, consistent with behavioral trade-offs in time allocation (Figure 3).

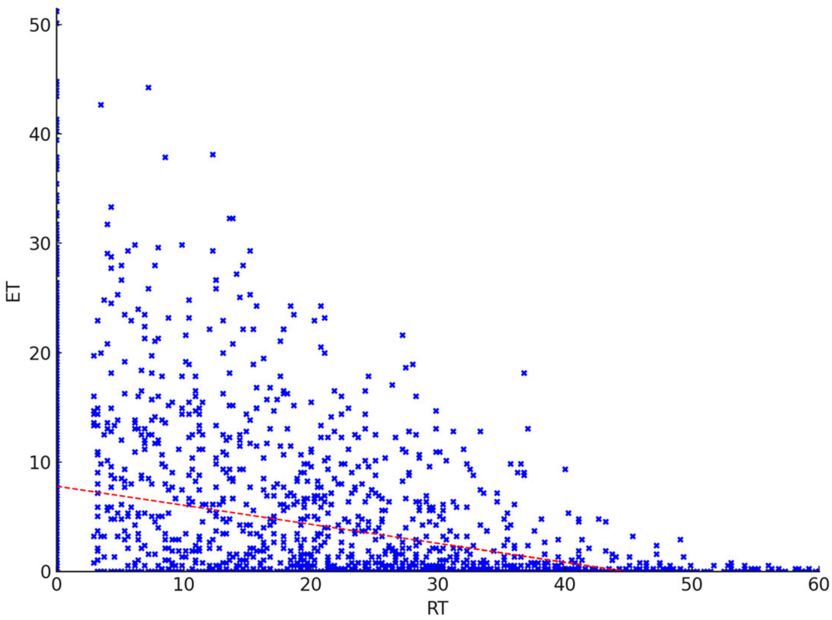

Figure 3. The relationship between Rumination time and Eating time. ET—Eating time; RT—Rumination time. r = −0.54.

3.3. The Relationship Between Rumination Time and Rumination Chews

We observed a strong and significant positive correlation between rumination time (RT) and rumination chews (RC) (r = 0.84, $p < 0.001$). As RT increases, RC also increases (Figure 4).

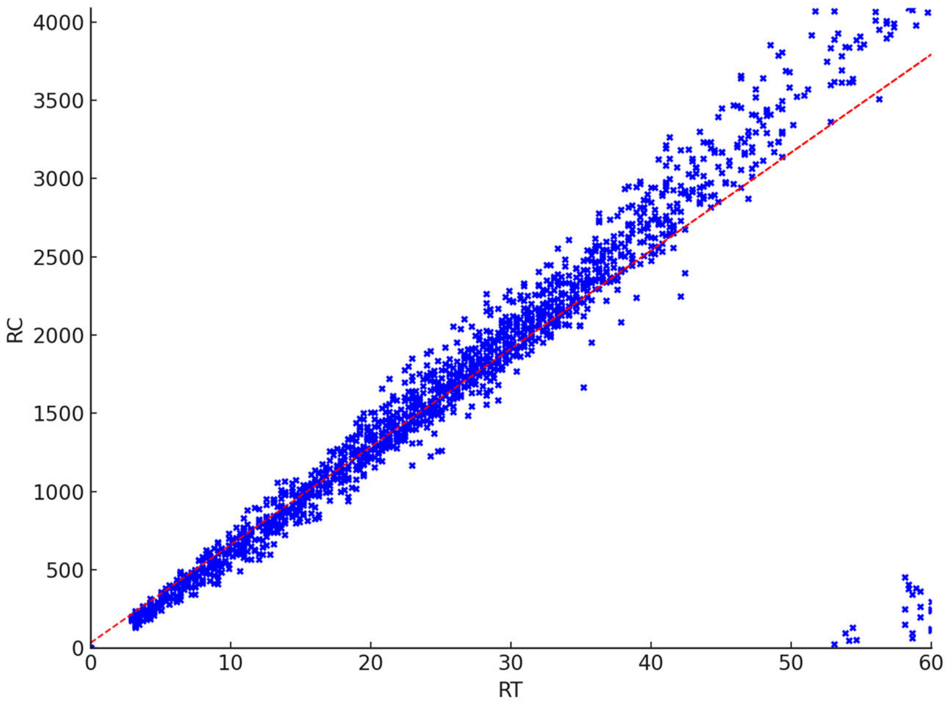

Figure 4. The relationship between Rumination time and Rumination chews. RC—Rumination chews; RT—Rumination time. r = 0.84.

3.4. The Relationship Between Rumination Time and Eating Chews

We found a negative association between rumination time (RT) and eating chews (EC). As RT increases, EC decreases. Spearman's correlation coefficient confirmed the association (r = −0.48, $p < 0.001$) (Figure 5).

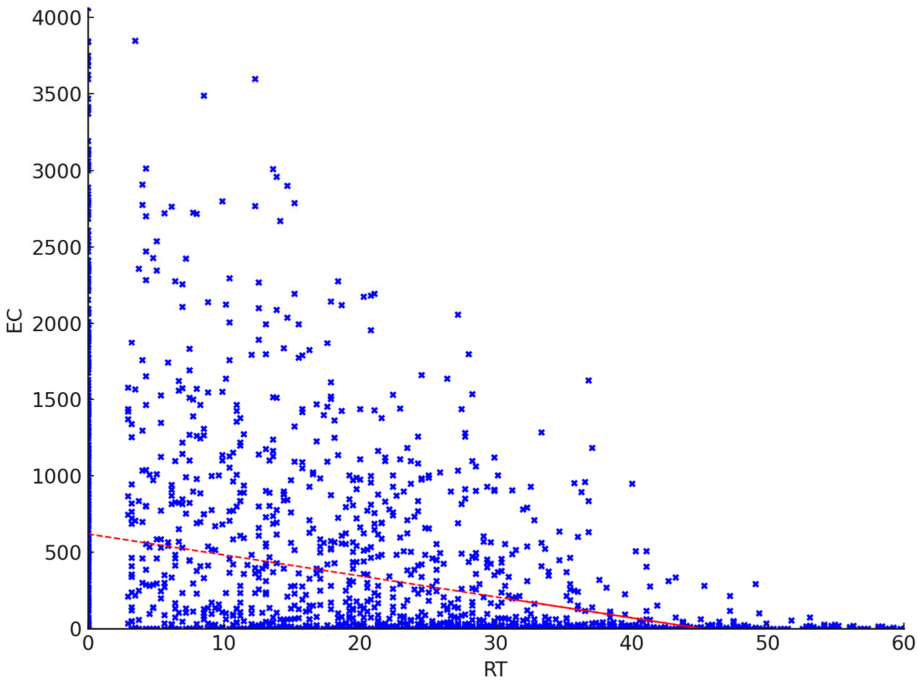

Figure 5. The relationship between Rumination time and Eating chews. EC—Eating chews, RT—Rumination time. r = −0.48.

3.5. The Relationship Between Rumination Time and Drinking Gulps

We found a statistically insignificant relation between RT and DG. Spearman's correlation coefficient validated the relationship (r = 0.10, $p > 0.05$) (Figure 6).

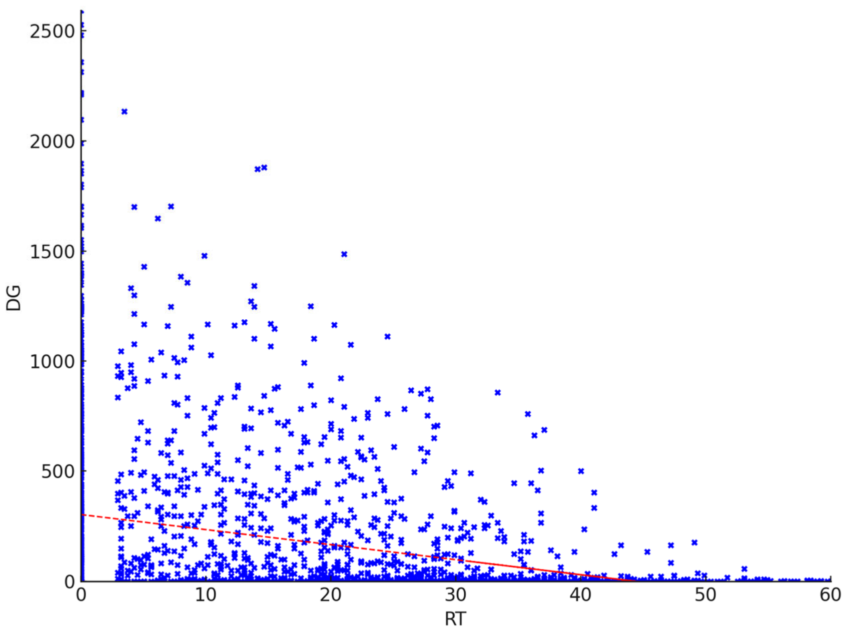

Figure 6. The relationship between Rumination time and Drinking gulps. DG—Drinking gulps, RT—Rumination time. r = 0.10.

3.6. The Relationship Between Rumination Time and Bolus

We observed a strong and significant positive correlation between rumination time (RT) and bolus (B) (r = 0.75, $p < 0.001$). This result underscores the close physiological connection between the duration of rumination and bolus formation, highlighting the efficiency of the ruminating process (Figure 7).

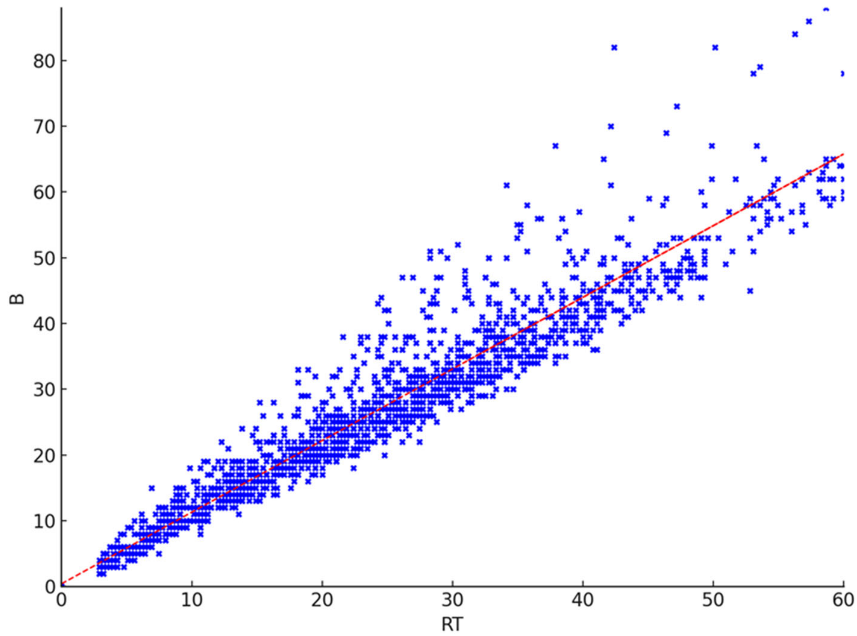

Figure 7. The relationship between Rumination time and Bolus. B—Bolus, RT—Rumination time. r = 0.75.

3.7. The Relationship Between Rumination Time and Chews per Minute

We determined a moderate, significant positive correlation between rumination time (RT) and chews per minute (CPM) (r = 0.29 $p < 0.05$). This finding highlights a subtle relationship, suggesting that increased rumination time may be associated with a slightly higher chewing rate (Figure 8).

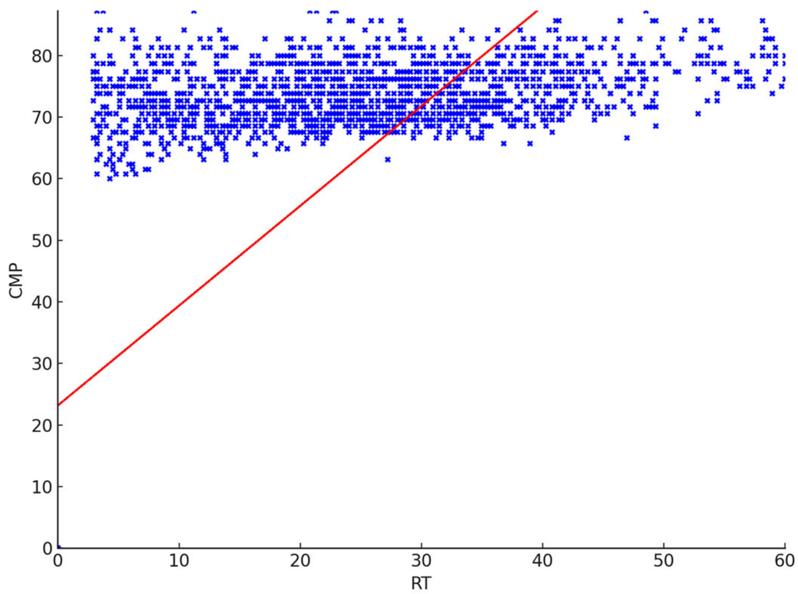

Figure 8. The relationship between Rumination time and Chews per minute. CPM—Chews per minute, RT—Rumination time. r = 0.29.

3.8. The Relationship Between Rumination Time and Activity

A moderate, significant negative correlation between rumination time (RT) and activity was identified (r = −0.34). This finding indicates that increased rumination time is associated with reduced activity levels, reflecting a behavioral trade-off between these parameters (Figure 9).

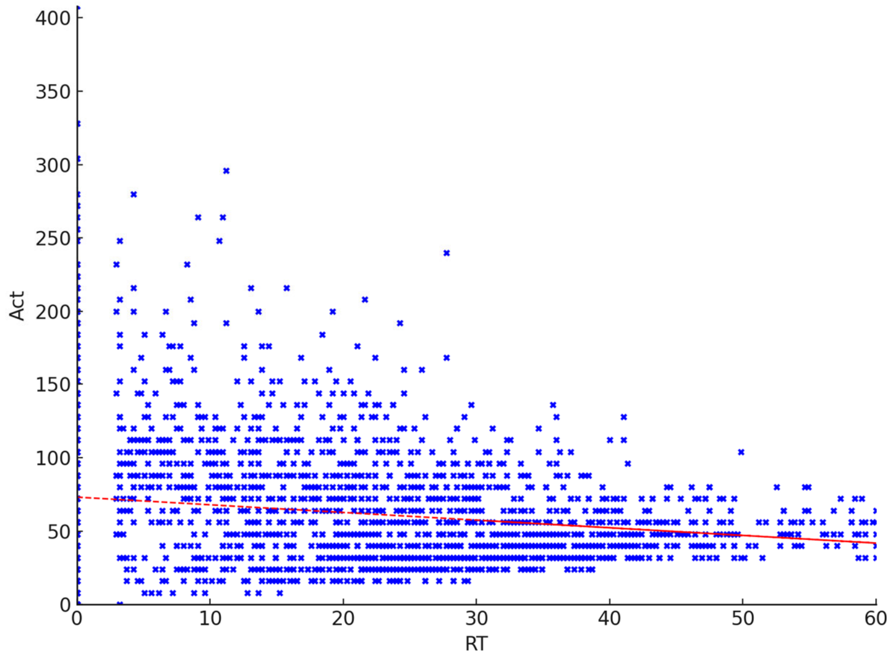

Figure 9. The relationship between Rumination time and Activity. A—Activity, RT—Rumination time. r = −0.34.

4. Discussion

The innovative technologies successfully tracked the eating, ruminating, and inactive behaviors of lactating dairy cattle and are anticipated to perform well in monitoring these behaviors within a commercial environment [15].

Reflecting on the aim of our study, which investigated the association between rumination time and various parameters of eating and locomotion, our findings indicate a significant negative relationship between rumination time and Other Activity Time (r = −0.65), Eating Time (r = −0.54), and Activity (r = −0.34). Moderate negative correlations were also observed with Eating Chews (r = −0.48). Interestingly, the relationship with Drinking Gulps was not significant (r = 0.10). In contrast, strong positive correlations were identified between rumination time and Rumination Chews (r = 0.84) as well as Bolus (r = 0.75). A weaker positive correlation was found with Chews Per Minute (r = 0.29). These results underline the complexity of behavioral trade-offs in dairy cows, where time allocated to rumination is closely linked to variations in other activities, reflecting the intricate balance of physiological and behavioral processes.

We found a significant negative relationship between rumination time (RT) and other activity time (OAT), such that as RT increases, OAT decreases (r = −0.65). This inverse association highlights a behavioral trade-off, where increased time spent ruminating reduces the duration allocated to other non-ruminating activities. Cattle with longer periods of ruminating tend to engage in fewer social and physical activities [11]. In studies conducted by other scientists, it has been shown that dairy cows with illnesses like metritis exhibit lower levels of activity and rumination, suggesting that health state might affect both RT and OAT [5]. The social hierarchy among cows can also impact rumination, as cows of a lower rank may eat less, leading to reduced rumination, decreased lying down, and increased standing [10].

We detected a significant negative relationship between rumination time (RT) and eating time (ET), such that as RT increases, ET decreases (r = −0.54). This finding underscores the behavioral trade-off between time spent ruminating and time allocated to eating activities. The negative correlation between RT and ET in ruminants has been reported in research conducted by other scientists; for example, a study by Mertens revealed that the amount of time spent eating reduced as the amount of time spent ruminating grew, underscoring the trade-off between these two crucial activities [15]. The idea that increased RT reduces feeding possibilities was further supported by a study by Stangaferro et al., which found that cows with longer ruminating rates also had considerably shorter eating times [5]. This negative association was further supported by Verdon et al., who discovered that cows with restricted feeding times displayed higher RT and lower ET [16]. The duration of feeding among dairy cattle exhibits significant variability across various experimental setups. In a comprehensive review of data on dairy cows from peer-reviewed studies, White et al. [17] observed an average feeding time of 284 min per day (based on 182 observations), with a range extending from 141 to 507 min daily. This variation could be partially attributed to the slightly different methodologies employed in these studies for determining feeding time. Additionally, factors such as feed management strategies, dry matter intake (DMI), as well as the physical and chemical properties of the feed, alongside the natural differences among individual animals, significantly influence feeding time [18]. Environmental conditions also significantly influence feeding time: for example, elevated ambient temperatures can modify feeding patterns, causing cattle to concentrate their feeding during cooler times of the day, such as dawn and dusk. This adjustment in behavior may elevate the risk of issues like sub-acute ruminal acidosis due to altered feeding habits [11]. A compensatory dynamic exists between the duration of eating and rumination. Ref. [11] found that among dairy cows with free access to feed, there was a negative correlation (−0.62) between eating and rumination times, suggesting cows that eat for shorter periods tend to spend more time ruminating. This inverse relationship was also observed in situations where cows had reduced eating times due to restricted feeding or the composition of their diet; an increase in rumination time was noted as a compensatory mechanism for the larger feed particles consumed under restricted feeding conditions [19]. Consequently, the total time spent chewing tends to be more consistent than the individual times spent eating or ruminating. Nevertheless, this compensatory mechanism might not be present if cows are ruminating at or near their physiological limit, which is often the case with high-yielding dairy cows. As a result, the correlation between eating and ruminating times across various studies has been relatively low [17]. The estimated maximum total chewing time for dairy cows is around 16 h per day [20].

We observed a strong and significant positive correlation between rumination time (RT) and rumination chews (RC) ($r = 0.84$). This result highlights the close association between the duration of rumination and the number of chews, reflecting the physiological efficiency of this behavior. The number of chews per bolus tends to increase as RT rises, suggesting a compensatory process in which more thorough chewing is linked to longer ruminating times [11]. Cows' behaviors also have an impact on the link between RT and RC. Cows frequently ruminate while lying down, a habit that facilitates relaxation and effective digestion [12]. Since chewing is an essential part of the rumination process, more RT always results in more chews [21]. The physical characteristics of the meal as well as the cow's general health and wellbeing are the causes of this behavior. As an example, cows in good health had longer RT and greater RC than cows with metabolic problems or mastitis [13]. We found a strong, significant negative correlation between rumination time and eating chews. There is no discernible relationship between dry matter intake and the amount of time spent feeding, ruminating, or chewing overall throughout various cow-period observations [22]. In particular, they discovered that whereas eating duration was negatively correlated with DMI, this does not necessarily imply that longer meal times are associated with more chewing or ruminating time [23]. This suggests that there may be a negative relationship between these two activities as cows reduce their ruminating time to make up for their increased feeding time. Furthermore, the findings of scientists lend credence to the notion that eating and ruminating behaviors may be adversely affected by heat stress [7]. They found that cows reduced their chewing and ruminating time during heat stress, suggesting that environmental stresses might interfere with the typical relationship between these two behaviors [7]. Ruminating time and chewing time may be positively correlated in some situations, but there are other times when a negative association is shown. The nature of this association is influenced by a number of important factors, including environmental factors, health status, and dietary composition. The duration of both eating and rumination is influenced by the diet's chemical and physical properties. However, other variables like feeding management practices, individual differences among cows, and their health status can also significantly impact chewing time. These factors are often not accounted for in models predicting chewing time. Chewing plays a vital role in stimulating salivation, reducing particle size, aiding microbial digestion, and facilitating the passage of indigestible materials from the rumen, yet quantifying the impact of variations in chewing time on these processes can be challenging [11]. The advent of affordable sensors capable of tracking dairy cows' chewing activities in commercial settings offers valuable data that can enhance management decisions, particularly when used alongside other indicators [11].

We found no significant correlation between rumination time (RT) and drinking gulps (DG) ($r = 0.10$). This indicates that the duration of rumination does not have a strong impact on the number of drinking gulps, highlighting the independence of these behaviors. Scientists evaluated the eating and rumination behavior of 300 cows from three different breeds using a noseband pressure sensor. They observed that disturbances in drinking routines, such as an insufficient water supply, adversely affected feeding and rumination habits [24]. This highlights the critical link between adequate hydration and efficient rumination. Proper water availability is therefore essential for maintaining optimal feeding behaviors and digestive health in dairy cattle [22]. Researchers discovered that drinking behavior is linked to total productivity since longer periods of rumination are associated with higher milk production, which in turn requires larger water consumption [24]. Rumination and drinking are also significantly influenced by environmental conditions, especially heat stress. According to our previous study, high temperatures cause cows to ruminate less and drink less, which suggests that thermal stress might interfere with regular eating habits [25]. This can be linked to the physiological responses to heat stress, which include reduced activity levels and decreased feed intake, potentially affecting water consumption indirectly. When cattle experience discomfort due to high temperatures, their overall activity diminishes, possibly leading to less frequent drinking [26].

We observed a strong and significant positive correlation between rumination time (RT) and bolus ($r = 0.75$). This result emphasizes the close relationship between the duration of rumination and the physiological process of bolus formation, reflecting the efficiency and consistency of ruminating behavior.

According to other studies, the number of boluses and ruminating duration are significantly positively correlated. Scientists provided more evidence for this association by showing a strong correlation between eating patterns and rumination, with a higher frequency of boluses frequently being connected to longer periods of ruminating. They pointed out that cows ruminate more efficiently when they are lying down, which enables them to digest and swallow food more thoroughly and results in more boluses [27]. This implies that the cow's physical position during rumination could promote a more effective digestive process. Further highlighting the significance of bolus management in conjunction with rumination time, other researchers also validated the use of rumination collars, and the study found that precise rumination monitoring can offer insights into the health and feeding efficiency of dairy cows [11]. We determined a strong, significant positive correlation between rumination time and chews per minute. Primiparous cows, for example, had longer rumination and overall chewing durations than multiparous cows [22]. This suggests that younger cows chew more thoroughly, as seen by higher chew counts. A strong, significant negative correlation between rumination time and activity was identified. In ruminants, rumination is crucial for efficient digestion, and activity levels might reveal an animal's overall health and metabolic state. For instance, in the early postpartum phase, cows with health problems such as ketosis showed reduced activity levels and rumination length, and specifically observed that from five days prior to calving to two days postpartum, cows with ketosis or metritis had significantly reduced levels of both rumination and activity [28]. This suggests that health disorders can negatively impact both rumination and activity, indicating a potential area for monitoring cow health through behavioral changes. Similarly, compared to healthy cows, cows with metritis had lower levels of activity and rumination time, according to Stangaferro et al. Since changes in rumination and activity patterns sometimes occur before clinical indications of sickness, their findings demonstrated that tracking these behaviors might be a useful technique for early health condition detection [5].

As a limitation, it should be noted that this study does not account for how variables such as the cow's stage of lactation, number of lactations, milk production, and pregnancy status may influence the parameters measured by the RumiWatch System, potentially affecting the accuracy of its findings.

Notably, the observed trend in Figure 4, where rumination chew (RC) values are close to zero during maximum rumination times (60 min), may be attributed to specific biological behaviors. Prolonged rumination periods without active chewing could occur during resting phases or transitional activities, where cows might engage in passive rumination without continuous chewing. This variation aligns with natural patterns in rumination behavior and highlights the complexity of these physiological processes. Further investigation is warranted to explore these prolonged rumination periods in greater detail, particularly to differentiate between active chewing and passive rumination phases. Understanding these nuances can enhance the interpretation of sensor-derived data and contribute to a more comprehensive assessment of dairy cow health and welfare.

Therefore, to ensure the most accurate data, it is essential to properly calibrate the RumiWatch system for each cow. Correct sensor placement on the noseband is crucial for accurately tracking movements such as rumination, eating, and drinking. Additional indicators alongside RumiWatch are vital for a comprehensive assessment of dairy cow health, productivity, and welfare. Monitoring body condition score (BCS) and milk composition provides valuable insights into an animal's energy reserves and nutritional status, particularly in relation to the demands of lactation. BCS changes are often linked to postpartum negative energy balance, which can significantly influence fertility and reproductive outcomes [29].

Additionally, it overlooks the impact of social hierarchy among cows on rumination behavior, which could lead to variations in eating, lying down, and standing times not considered in the analysis. Future studies should consider incorporating variables such as the stage of lactation, number of lactations, milk production, and pregnancy status into their analysis to understand better their impact on the parameters measured by technologies like the RumiWatch System. Additionally, research should aim to investigate the influence of social hierarchy among dairy cows on rumination and feeding behaviors, potentially through direct observation or advanced sensor technologies, to provide a more comprehensive understanding of factors affecting cow health and productivity.

5. Conclusions

In conclusion, this study highlights the utility of innovative technologies like the RumiWatch System in understanding the intricate relationship between rumination time and various eating and locomotion parameters in dairy cows, providing deeper insights into how different aspects of cow behavior are interconnected.

Our findings suggest that increased rumination time is significantly associated with reduced other activity time and eating time, indicating a behavioral trade-off between rumination and these activities. Positive correlations were observed between rumination time and rumination chews ($r = 0.84$) as well as bolus ($r = 0.75$), emphasizing the physiological connection between these behaviors. Additionally, a weaker positive correlation with chews per minute ($r = 0.29$) further underscores the multifaceted nature of rumination. However, no significant correlation was found between rumination time and drinking gulps ($r = 0.10$), highlighting the independence of these behaviors.

Adopting such technology in dairy farm management can provide crucial insights by enabling early detection of health issues via changes in rumination and eating patterns. This has the potential to improve animal welfare and herd productivity through better management practices. The significant correlations identified in this study underscore the importance of continuous monitoring of these parameters for maintaining the health and efficiency of dairy operations. Ultimately, these insights can guide data-driven decisions that enhance herd health and farm profitability.

Author Contributions: R.A.: supervision of the whole study, K.D., J.K., G.Š. and G.L.: writing—review and editing and software; S.A., A.G., K.T. and R.J.: data collection and investigation; G.P., W.B. and A.L.: review and editing. All authors have read and agreed to the published version of the manuscript.

Funding: Lithuanian Council for Research. Project identification: S-MIP-22-137.

Institutional Review Board Statement: This study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Ethics Committee (the study approval number is PK016965. 6 June 2017).

Data Availability Statement: Data is contained within the article.

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

References

1. Stygar, A.H.; Gómez, Y.; Berteselli, G.V.; Dalla Costa, E.; Canali, E.; Niemi, J.K.; Llonch, P.; Pastell, M. A Systematic Review on Commercially Available and Validated Sensor Technologies for Welfare Assessment of Dairy Cattle. *Front. Vet. Sci.* **2021**, *8*, 634338. [CrossRef] [PubMed]
2. Berckmans, D. General Introduction to Precision Livestock Farming. *Anim. Front.* **2017**, *7*, 6–11. [CrossRef]
3. Rutten, C.J.; Velthuis, A.G.J.; Steeneveld, W.; Hogeveen, H. Invited Review: Sensors to Support Health Management on Dairy Farms. *J. Dairy Sci.* **2013**, *96*, 1928–1952. [CrossRef] [PubMed]
4. King, M.T.M.; LeBlanc, S.J.; Pajor, E.A.; DeVries, T.J. Cow-Level Associations of Lameness, Behavior, and Milk Yield of Cows Milked in Automated Systems. *J. Dairy Sci.* **2017**, *100*, 4818–4828. [CrossRef]
5. Stangaferro, M.L.; Wijma, R.; Caixeta, L.S.; Al-Abri, M.A.; Giordano, J.O. Use of Rumination and Activity Monitoring for the Identification of Dairy Cows with Health Disorders: Part III. Metritis. *J. Dairy Sci.* **2016**, *99*, 7422–7433. [CrossRef]
6. McArt, J.A.A.; Nydam, D.V.; Oetzel, G.R. Epidemiology of Subclinical Ketosis in Early Lactation Dairy Cattle. *J. Dairy Sci.* **2012**, *95*, 5056–5066. [CrossRef]
7. Calamari, L.; Soriani, N.; Panella, G.; Petrera, F.; Minuti, A.; Trevisi, E. Rumination Time around Calving: An Early Signal to Detect Cows at Greater Risk of Disease. *J. Dairy Sci.* **2014**, *97*, 3635–3647. [CrossRef]
8. Pereira, G.M.; Sharpe, K.T.; Heins, B.J. Evaluation of the RumiWatch System as a Benchmark to Monitor Feeding and Locomotion Behaviors of Grazing Dairy Cows. *J. Dairy Sci.* **2021**, *104*, 3736–3750. [CrossRef]
9. Zehner, N.; Umstätter, C.; Niederhauser, J.J.; Schick, M. System Specification and Validation of a Noseband Pressure Sensor for Measurement of Ruminating and Eating Behavior in Stable-Fed Cows. *Comput. Electron. Agric.* **2017**, *136*, 31–41. [CrossRef]

10. Pahl, C.; Hartung, E.; Grothmann, A.; Mahlkow-Nerge, K.; Haeussermann, A. Rumination Activity of Dairy Cows in the 24 Hours before and after Calving. *J. Dairy Sci.* **2014**, *97*, 6935–6941. [CrossRef]
11. Llonch, P.; Mainau, E.; Ipharraguerre, I.R.; Bargo, F.; Tedó, G.; Blanch, M.; Manteca, X. Chicken or the Egg: The Reciprocal Association Between Feeding Behavior and Animal Welfare and Their Impact on Productivity in Dairy Cows. *Front. Vet. Sci.* **2018**, *5*, 305. [CrossRef] [PubMed]
12. Borchers, M.R.; Chang, Y.M.; Proudfoot, K.L.; Wadsworth, B.A.; Stone, A.E.; Bewley, J.M. Machine-Learning-Based Calving Prediction from Activity, Lying, and Ruminating Behaviors in Dairy Cattle. *J. Dairy Sci.* **2017**, *100*, 5664–5674. [CrossRef] [PubMed]
13. Goldhawk, C.; Chapinal, N.; Veira, D.M.; Weary, D.M.; von Keyserlingk, M.A.G. Prepartum Feeding Behavior Is an Early Indicator of Subclinical Ketosis. *J. Dairy Sci.* **2009**, *92*, 4971–4977. [CrossRef]
14. Antanaitis, R.; Juozaitienė, V.; Urbonavičius, G.; Malašauskienė, D.; Televičius, M.; Urbutis, M.; Baumgartner, W. Impact of Lameness on Attributes of Feeding Registered with Noseband Sensor in Fresh Dairy Cows. *Agriculture* **2021**, *11*, 851. [CrossRef]
15. Mertens, D.R. Creating a System for Meeting the Fiber Requirements of Dairy Cows. *J. Dairy Sci.* **1997**, *80*, 1463–1481. [CrossRef]
16. Verdon, M.; Rawnsley, R.; Raedts, P.; Freeman, M. The Behaviour and Productivity of Mid-Lactation Dairy Cows Provided Daily Pasture Allowance over 2 or 7 Intensively Grazed Strips. *Animals* **2018**, *8*, 115. [CrossRef]
17. White, R.R.; Hall, M.B.; Firkins, J.L.; Kononoff, P.J. Physically Adjusted Neutral Detergent Fiber System for Lactating Dairy Cow Rations. I: Deriving Equations That Identify Factors That Influence Effectiveness of Fiber. *J. Dairy Sci.* **2017**, *100*, 9551–9568. [CrossRef]
18. Beauchemin, K.A. Invited Review: Current Perspectives on Eating and Rumination Activity in Dairy Cows. *J. Dairy Sci.* **2018**, *101*, 4762–4784. [CrossRef]
19. Dado, R.G.; Allen, M.S. Variation in and Relationships Among Feeding, Chewing, and Drinking Variables for Lactating Dairy Cows. *J. Dairy Sci.* **1994**, *77*, 132–144. [CrossRef]
20. Dulphy, J.P.; Remond, B.; Theriez, M. Ingestive Behaviour and Related Activities in Ruminants. In *Digestive Physiology and Metabolism in Ruminants, Proceedings of the 5th International Symposium on Ruminant Physiology, Clermont-Ferrand, France, 3–7 September 1979*; Ruckebusch, Y., Thivend, P., Eds.; Springer Netherlands: Dordrecht, The Netherlands, 1980; pp. 103–122, ISBN 978-94-011-8067-2.
21. Jensen, M.B. Behaviour around the Time of Calving in Dairy Cows. *Appl. Anim. Behav. Sci.* **2012**, *139*, 195–202. [CrossRef]
22. Naderi, N.; Ghorbani, G.R.; Sadeghi-Sefidmazgi, A.; Kargar, S.; Hosseini Ghaffari, M. Substitution of Corn Silage with Shredded Beet Pulp Affects Sorting Behaviour and Chewing Activity of Dairy Cows. *J. Anim. Physiol. Anim. Nutr.* **2019**, *103*, 1351–1364. [CrossRef] [PubMed]
23. Schmidt, A.P.; Vieira, L.V.; Barbosa, A.A.; Marins, L.; Corrêa, M.N.; Pino, F.A.B.D.; Brauner, C.C.; Rabassa, V.R.; Feijó, J.d.O.; Schmitt, E. Use of the Rumination Profile Through Collar Sensors for Mastitis Diagnosis in Dairy Cows. *Acta Sci. Vet.* **2021**, *49*, 1786. [CrossRef]
24. Braun, U.; Zürcher, S.; Hässig, M. Evaluation of Eating and Rumination Behaviour in 300 Cows of Three Different Breeds Using a Noseband Pressure Sensor. *BMC Vet. Res.* **2015**, *11*, 231. [CrossRef] [PubMed]
25. Mikuła, R.; Pszczola, M.; Rzewuska, K.; Mucha, S.; Nowak, W.; Strabel, T. The Effect of Rumination Time on Milk Performance and Methane Emission of Dairy Cows Fed Partial Mixed Ration Based on Maize Silage. *Animals* **2022**, *12*, 50. [CrossRef]
26. Antanaitis, R.; Džermeikaitė, K.; Šimkutė, A.; Girdauskaitė, A.; Ribelytė, I.; Anskienė, L. Use of Innovative Tools for the Detection of the Impact of Heat Stress on Reticulorumen Parameters and Cow Walking Activity Levels. *Animals* **2023**, *13*, 1852. [CrossRef]
27. Schirmann, K.; Weary, D.M.; Heuwieser, W.; Chapinal, N.; Cerri, R.L.A.; von Keyserlingk, M.A.G. Short Communication: Ru-mination and Feeding Behaviors Differ between Healthy and Sick Dairy Cows during the Transition Period. *J. Dairy Sci.* **2016**, *99*, 9917–9924. [CrossRef]
28. Habeeb, A.A.; Osman, S.F.; Teama, F.E.I.; Gad, A.E. The detrimental impact of high environmental temperature on physiological response, growth, milk production, and reproductive efficiency of ruminants. *Trop. Anim. Health Prod.* **2023**, *55*, 388. [CrossRef] [PubMed] [PubMed Central]
29. Steensels, M.; Bahr, C.; Berckmans, D.; Halachmi, I.; Antler, A.; Maltz, E. Lying Patterns of High Producing Healthy Dairy Cows after Calving in Commercial Herds as Affected by Age, Environmental Conditions and Production. *Appl. Anim. Behav. Sci.* **2012**, *136*, 88–95. [CrossRef]