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Abstract

Few portable devices that record grazing time have been tested on goats. The Lifecorder Plus is a commercial device, based on a single-axis accelerometer, that calculates and stores in memory the average activity level (range: 0-9) every 2 min. Previous studies determined that activity levels greater than or equal to 0.5 were specific to grazing, while those less than 0.5 could be considered as other activities. The aims of the present study were to determine the threshold value that minimised the prediction error and to validate the ability of the Lifecorder Plus device to record goat grazing time at vegetative temperate pasture under rotational grazing management. Twenty goats (5 in 2015 and 15 in 2017) were fitted with the Lifecorder Plus on their neck and had access to pasture for 8-12 h/d. The device was evaluated by comparing 2-min visual observations of trained observers to the activity level recorded at the same time by the device, resulting in a total of 187 h of observations. Two analysis methods were used to assess the device's accuracy: a confusion matrix and the mean squared prediction error. Lifecorder Plus recorded grazing time with 93% accuracy, 95% precision, 97% sensitivity and 73% specificity. Relative prediction errors calculated at the hour and day scales were low, averaging 0.09 and 0.05 of actual grazing time, respectively. Overall, there

was no confusion between grazing and other goat activities. Lifecorder Plus overestimated grazing time by 3%, probably due to other activities of goats (lack of specificity). Placing an additional Lifecorder Plus on a leg may help identify non-grazing activities (e.g. long-duration walking, running) and thus reduce this slight overestimation. No bias due to sward height was detected. In conclusion, for rotationally grazed vegetative temperate pastures, Lifecorder Plus detects grazing activities of goats with high accuracy and precision and is suitable for studying variations in grazing time, particularly at the day scale in small paddocks.

Keywords: Grazing time, Dairy goat, Accelerometer, Lifecorder Plus, Behaviour

1. Introduction

In Western Europe, increasing grazing in dairy goat production systems can improve feed self-sufficiency and reduce the influence of feed prices on profit (Ruiz et al., 2009; Brocard et al., 2016). However, grazing raises issues, in particular for grazing-management practices and animal performance, health and welfare, such as parasitic infestations in small ruminants (Hoste et al., 2002). To achieve high pasture intake, either per goat or per ha, it is important to know the ability of dairy goats to adapt to grazing and feeding conditions, such as sward height, daily pasture allowance, daily access time to pasture and supplementation level (Charpentier and Delagarde, 2018; Charpentier et al., 2019). Simultaneously recording individual pasture intake using animal-based techniques (Penning, 1991; Delagarde et al., 2018a) and grazing time using portable devices allows an average pasture intake rate to be estimated. This information improves understanding of how behavioural constraints regulate the intake of grazing dairy goats.

Portable electronic devices that record animal activities have become increasingly available over time. Many devices based on accelerometers are used to assess animal activities at pasture, either for research or for animal production, and most of them have been developed for cattle and sheep (Andriamandroso et al., 2016). Few devices have been tested on grazing dairy goats (Moreau et al., 2009; Sakai et al., 2019).

The Lifecorder Plus is a commercially available device based on a single-axis accelerometer that is designed to measure human activity (LCP, Suzuken Co. Ltd., Nagoya, Japan). Ten years ago, Ueda et al. (2011) and Yoshitoshi et al. (2013) suggested that the Lifecorder device could be useful for recording the grazing behaviour of dairy cows at pasture. Basically, the sensor samples acceleration at 32 Hz, and the acceleration signal is filtered through an analogue band-pass filter and digitised (Kumahara et al., 2004). The device takes the maximum pulse over 4 s as the acceleration signal and uses proprietary algorithms to process the raw signal into an activity level in the range of 0.0 (no activity) to 9.0 (constant activity). The algorithms and methods used to process the raw signal have not been published. Before each use of the Lifecorder Plus, the user must initiate the device with the Physical Activity Analysis Software Lifestyle Coach v1.2 (Kenz, Suzuken Co. Ltd., Nagoya, Japan). The user must choose one of two recording options: the mode or the average activity level of each 2-min period, considering the 30 values recorded every 4 s. Preliminary tests showed that only the average activity level was useful for recording grazing time. Consequently, we chose this option in the present study, as we had for dairy cows (Delagarde and Lamberton, 2015). In this previous study, the Lifecorder Plus was validated for grazing dairy cows with 250 h of visual observations and showed high accuracy and a low mean prediction error (MPE) of ca. 0.05 at the day scale. The device was placed in a box attached to a collar around the cow's neck, and grazing activities were detected mainly from head acceleration. Cows were considered to be grazing when the activity level was greater than or equal to 0.5 (scale: 0-9). At the beginning of the present study, several full 24-h days were recorded, including indoor housing at night and grazing during the daytime, with short (8 h/d) to long (14 h/d) daily access to pasture (Figure 1). We observed in this and previous grazing goat studies (Charpentier and Delagarde, 2018; Delagarde et al., 2018b; Charpentier et al., 2019) that the signal recorded on goats was similar to that recorded on cows (Delagarde and Lamberton, 2015), with a baseline signal close to zero. Thus, we defined grazing periods of goats as periods with an activity level greater than a given threshold. In our previous studies, we used the same threshold (0.5) for goats as for cows after preliminary comparison of actual and recorded grazing time. The objectives of the present study were to determine (1) the ability of the Lifecorder Plus to detect grazing activities, in order to estimate daily grazing time of dairy goats rotationally grazing vegetative temperate grasslands, and (2) the threshold value that minimised the MPE of the grazing time estimate.

{Insert Figure 1 approximately here}

2. Materials and methods

21. Experimental site, goats and management

This validation study was performed in spring 2015 and spring 2017 at the Institut National de la Recherche pour l'Agriculture, l'Alimentation et l'Environnement (INRAE) experimental dairy farm of Méjusseaume (1.71°W, 48.11°N, Le Rheu, Brittany, France). The study used 20 focal animals, all Alpine dairy goats in mid-lactation. The focal animals were chosen at random from herds of 12-60 goats, depending on the period. The herds were rotationally grazed on multispecies pastures composed of sown perennial ryegrass (*Lolium perenne* L.), tall fescue (*Festuca arundinacea* Schreb.), lucerne (*Medigo sativa* L.), white clover (*Trifolium repens* L.) and chicory (*Cichorium intybus* L.), as well as unsown dandelion (*Taraxacum officinale* L.). Goats were milked twice daily, from 07:00 to 08:00 in the morning and 16:30 to 17:30 in the evening. They had access to pastures between morning and evening milkings, and sometimes for 3-4 hours after the evening milking before nightfall. The front electric fence was moved once every 1-2 days in 6000 m² paddocks to provide fresh pasture regularly (Charpentier and Delagarde, 2018). The focal goats were permanently fitted with the Lifecorder Plus during the study. The device was placed in a small waterproof plastic box (90 mm × 60 mm × 55 mm) attached to a plastic collar that was placed around the goat's neck. The device was oriented in the box to lie in a standard horizontal position when the goat was in a head-up position in order to record head movements better when the goats grazed in a head-down position. Any head movement that creates acceleration during grazing will be translated into activity, but the most frequent movements that create the most activity are vertical and/or horizontal head-jerks while biting. The collar was cinched loosely to allow the box to move freely and to maximise sensor recording (Delagarde and Lamberton, 2015). Each visual observation period, hereafter called a "sequence", entailed continuous tracking of a goat by a trained observer. There were two trained observers in total, one in 2015 and one in 2017. Independent of these visual observations used to validate the Lifecorder Plus, in 2017, six additional goats were each fitted with three Lifecorder Plus in different locations: neck, fore leg and hind leg. The aim of these additional observations was to highlight differences in the signals recorded at the neck and legs in order to analyse sources of bias of the Lifecorder Plus that may have been related to other activities. During these additional observations, the observer sometimes forced the goats into active movement (e.g. walking, running) for a few minutes. The observer recorded all active movements in addition to grazing and rumination. These additional observations were not included in the dataset used to validate the device because the observer had disturbed the goats.

22. Measurements

The focal goats' activities were recorded manually and divided into three categories: "Grazing", "Rumination" and "Other activities". Goats were considered to be grazing when they were biting head down, walking slowly in a head-down position (searching) with or without chewing, or chewing head up after a biting period. Rumination, defined as a period of mastication of boluses, was identified by chewing without grazing and regular regurgitation of boluses. "Other activities" corresponded to all other goat activities (i.e. drinking, walking without grazing, running, resting and social interactions). The dominant activity of each minute of observation was manually recorded at the end of the minute. For example, if a goat walked, ran or drank for 20 sec during a minute of grazing, these activities were included in the "Grazing" activity. In 2017 only, the compressed sward height was measured using a rising plate meter (30 × 30 cm, 4.5 kg/m², Aurea Agrosciences, Blanquefort, France), with 30 measurements made at the start of each observation sequence. The observer always remained quiet and sufficiently close (i.e. within a few meters) to the observed goat to record its activities accurately, and never disturbed natural animal behaviour. For a given observation day (n = 24, Table 1), observations were performed in the morning, in the afternoon or both. The validation dataset comprised 187 h of visual observations, which were divided among 69 sequences, 20 goats, 24 observation days (dates) and 12 Lifecorder Plus devices (Table 1).

{Insert Table 1 approximately here}

Once the recordings were made, the device was removed from the box and connected to a computer to transfer data via a USB cable. The data were downloaded using the Physical Activity Analysis Software Lifestyle Coach v1.2. The mean activity level for each 2-min period was stored in a CSV file.

23. Calculations

To compare Lifecorder Plus data (2-min frequency) to visual observation data (1-min frequency) at the same temporal scale, all 2-min observation periods with at least 1 min of "grazing" activity were considered to be "grazing" activity (i.e. grazing was the dominant activity). Observations were performed only at pasture, as no activity could be detected indoors due to a lack of clear and regular head movements, which indicated that the device cannot determine eating time indoors. Analyses of the recorded data clearly showed that the activity level was close to zero when goats were ruminating or engaged in other activities. Grazing activities were thus characterised and defined by an activity level greater than or equal to a given threshold, as defined for dairy cows (Delagarde and Lamberton, 2015) and in the preliminary study of dairy goats (Charpentier and Delagarde, 2018). To choose the threshold value that minimised prediction error, two statistical methods were applied for threshold values ranging from 0.0-1.2.

24. Statistical analyses

The two statistical methods used to assess the accuracy of the Lifecorder Plus were a confusion matrix (Mansbridge et al., 2018; Alvarenga et al., 2020) and the mean squared prediction error (MSPE) (Bibby and Toutenburg, 1977).

- Confusion matrix (method 1)

The confusion matrix was generated from predicted (Lifecorder Plus) and actual (observations) values (grazing or non-grazing). The four classification options for each 2-min validation period were True Positive (TP), True Negative (TN), False Positive (FP) and False Negative (FN). The TP and FN are the number of instances in which the actual periods of grazing activities are classified correctly (e.g. as grazing) or incorrectly (e.g. as non-grazing), respectively. In contrast, TN and FP are the number of instances in which the actual periods of non-grazing activities are classified correctly (e.g. as non-grazing) or incorrectly (e.g. as grazing), respectively (Mansbridge et al., 2018; Alvarenga et al., 2020). From this classification, sensitivity, specificity, precision, accuracy and the F1 score were calculated using the following equations:

$$\text{Sensitivity (\%)} = (TP/(TP+FN)) \times 100$$

$$\text{Specificity (\%)} = (TN/(TN+FP)) \times 100$$

$$\text{Precision (\%)} = (TP/(TP+FP)) \times 100$$

$$\text{Accuracy (\%)} = ((TN + TP)/(TN+TP+FN+FP)) \times 100$$

$$\text{F1 score} = 2 \times ((\text{Precision} \times \text{Sensitivity})/(\text{Precision} + \text{Sensitivity}))$$

Sensitivity describes the percentage of actual grazing periods that the device correctly identified. Specificity describes the percentage of actual non-grazing periods that the device correctly identified. Precision describes the percentage of total predicted grazing time that is actual grazing time (Nielsen, 2013). Accuracy describes the percentage of correct classification across both activities (Mansbridge et al., 2018). The F1 score indicates performance of the device as a harmonic mean of the sensitivity and precision (Sakai et al., 2019; Saranya et al., 2020).

- Mean squared prediction error (method 2)

The MSPE and relative contributions of mean bias, line bias and random variation to it were calculated for predicted (Lifecorder Plus) and actual (observations) values according to Bibby and Toutenburg (1977). Mean bias is the mean difference between predicted and actual values. A positive (or negative) mean bias indicates that the device overestimates (or underestimates) the actual values. The line bias is the deviation of the slope of the regression line between actual vs. predicted values from that of the 1:1 line. A large line bias indicates mainly an inadequate model structure, with MSPE changing as a function of the actual value. The random variation is the percentage of the MSPE not related to the mean or line biases. The MPE is the square root of the MSPE, while relative prediction error (RPE) is the MPE divided by the mean actual grazing time. A low RPE and low contributions of both mean bias and line bias to the MSPE indicate high accuracy (Rook et al., 1990). The RPE may depend on the temporal scale of validation. At the day scale, the device could be considered moderately accurate, accurate or very accurate when RPE was 0.10-0.15, 0.05-0.10 or less than 0.05, respectively (Rook et al., 1990). Accuracy was analysed at five time scales by summing (before the analyses) the actual and predicted values of grazing time per hour (n=187), per sequence (n=69), per date (n=24), per standardised day of 8 h (n=24), per goat (n=20) and per Lifecorder Plus device (n=12). As the duration of the sequences differed depending on the day of observation, and because an average “grazing day” is 8 h/d in most goat grazing systems (i.e. indoors at night), observations from every 8 h period were summed to create standardised days.

3. Results

The duration of validation sequences averaged 162 min (range: 62-242 min) for a total of 69 observation sequences (total of 11,186 min or 5593 2-min periods). Recording time in the morning equalled that in the afternoon. On average, per hour of observation, the goats spent 49 min grazing, 2 min ruminating and 9 min in other activities, which represents 82%, 3% and 15% of their time spent grazing, ruminating and in other activities, respectively (Table 2). For the entire dataset, the frequency distribution of activity level recorded by the Lifecorder Plus during actual grazing periods differed completely from that observed during actual non-grazing periods (Figure 2). For example, the percentage of activity levels greater than 0.9, 0.7, 0.5, 0.3 and 0.1 were 91%, 95%, 97%, 98% and 100%, respectively, during actual grazing periods, but only 13%, 18%, 23%, 32% and 47%, respectively, during actual non-grazing periods. These frequency distributions suggested that a threshold in the range of 0.3-0.7 could distinguish grazing and non-grazing periods (Figure 2).

{Insert Figure 2 approximately here}

Sensitivity, specificity, precision, accuracy and MPE at the hour and sequence scales varied for threshold values ranging from 0.0-1.2 (Figure 3). By definition, for a threshold value of 0.0 (all activities considered to be grazing), sensitivity and specificity were 100% and 0%, respectively. Precision, the percentage of time the goats spent grazing during the observation periods, was 82% (Table 2). When the threshold increased from 0.0 to 1.2, sensitivity decreased from 100% to 85%, specificity increased from 0% to 90%, and precision increased from 82% to 98%. Accuracy was lowest at the extremes and peaked at 93% for the thresholds of 0.4 and 0.5. The RPE were largest at the extremes (> 0.20) and smallest at the threshold of 0.5 (0.091 and 0.074 at the hour and sequence scales, respectively). Consequently, the threshold was set at 0.5 for the rest of the present study.

{Insert Figure 3 approximately here}

{Insert Table 2 approximately here}

- Confusion matrix (method 1)

The Lifecorder Plus had a mean accuracy of 93% (Table 3). It correctly recognised 97% of the actual grazing 2-min periods (sensitivity), but only 73% of the non-grazing (rumination and other activities) periods (specificity). It correctly identified 95% of grazing time as grazing time (precision). The F1 score was nearly 96%.

{Insert Table 3 approximately here}

- Mean squared prediction error (method 2)

At each scale of validation, the total grazing time observed was similar to that recorded by the Lifecorder Plus (Figure 4, Table 4). Slopes of the relationship between predicted and actual grazing time ranged from 0.94-0.98, with coefficients of determination of the regressions ranging from 0.89-0.99, depending on the scale. The RPE ranged from 0.04-0.09, depending on the scale (Table 4). At the hour scale, the RPE was 0.09, indicating an error of 4.5 min, with 92% of MSPE due to random variation. At the day scale, the RPE was only 0.05 (19 min of error per standardised day), with 72% and 23% of MSPE due to random variation and mean bias, respectively. The actual grazing time was overestimated by 2.6% (i.e. 10 min) per standardised day (Table 4).

{Insert Figure 4 approximately here}

{Insert Table 4 approximately here}

An hour seems an appropriate scale for detecting problems in recorded grazing activities and for visualising the results. It represents the sum of thirty 2-min periods, thus decreasing the influence of any short-term random errors. Moreover, in a given hour, goats may engage exclusively in grazing activities or non-grazing activities, which enables sources of bias to be detected easily. At this finest scale of validation, no source of variation in the mean bias between Lifecorder Plus times and actual grazing times was identified. This bias was not strongly correlated with the time of actual grazing, ruminating or other activities, or with sward height (Figure 5). The contribution of line bias to the MSPE was extremely low (1%) at the hour and sequence scales. Actual grazing periods generally coincided well with the periods of high activity that the Lifecorder Plus recorded at the neck. In contrast, activity levels recorded at the legs were often low during most grazing periods (Figure 6). As the activity levels recorded at the fore and hind legs were similar and followed the same pattern, the two signals were averaged to compare them to the signal recorded at the neck (Figure 6). Other active behaviours (e.g. running, long walking times) generated high activity levels for all three locations of the Lifecorder Plus (neck, fore leg, hind leg).

{Insert Figure 5 approximately here}

{Insert Figure 6 approximately here}

4. Discussion

The accelerometer values stored by the Lifecorder Plus device make it possible to distinguish grazing activities from non-grazing activities at a 2-min resolution with 93% accuracy. It accurately recorded the time that goats spent grazing, regardless of the scale of validation. As the percentage of MSPE due to line bias was low, the MSPE does not depend on the actual grazing time recorded, which indicates that the device detects grazing activities well. The longer the validation time, the greater the accuracy of the Lifecorder Plus, because the MSPE is due mainly to random error. The longer the period, the more random errors cancel each other out. Consistent with our observations, the random error may have been due mainly to differences in the position of the box, which sometimes moved to the side of the neck for a few minutes. This probably decreased the acceleration and amplitude of the activity level, as the collar was cinched loosely to maximise box movement. The RPEs of 0.09 and 0.05 at the hour and day scales, respectively, are low and similar to those reported for dairy cows (Delagarde and Lamberton, 2015). This RPE was not highly sensitive to the threshold value of 0.5, as thresholds of 0.4 and 0.6 also had low RPE, and thresholds of 0.3 and 0.7 had RPE only slightly higher. This shows the robustness of the simple definition of grazing chosen in this study and the clear distinction of grazing vs. non-grazing activities based on the activity level recorded by the Lifecorder.

Comparing the accuracy of several devices is difficult due to large differences in validation methods, including the statistical approach and scale(s) of validation (as in our study), the frequency of recording actual behaviour and of comparing actual and predicted behaviour (from 5 sec to 15 min: Nielsen, 2013; González et al., 2015; Werner et al., 2019) and the number of behaviours studied (from 1-5: Nielsen, 2013; Gonzalez et al., 2015; Delagarde and

Lamberton, 2015). For example, when the recording frequency used to evaluate a 3D activity sensor was changed from 5 s to 10 min, Nielsen (2013) observed that precision increased from 75% to 84%, specificity increased from 80% to 92%, but sensitivity decreased from 84% to 59%.

When used under the conditions of this study, the Lifecorder Plus can be clearly considered as precise (95%) and sensitive (97%) for recording grazing time. In comparison, a 3-axis accelerometer previously tested on goats correctly classified grazing with 85% precision (Moreau et al., 2009). For dairy cows, the precision was nearly 98% for the CSIRO collar (González et al., 2015), 91% for an ear tag (Pereira et al., 2020) and 86% for the 3D activity sensor (Nielsen, 2013). The accuracy of the Lifecorder Plus (93%) can also be considered as high compared to the 90% accuracy of the RumiWatch device tested on cows (Steinmetz et al., 2020). The F1 score of the Lifecorder Plus (96%) indicates high performance when compared to a 9-axis multi-sensor accelerometer tested on goats (Sakai et al., 2019). The Lifecorder Plus showed lack of specificity (73%), however, like other devices, such as the 3-axis activity sensor tested on dairy cows (80%, Nielsen, 2013). To our knowledge, the specificity of devices used to record the grazing time of dairy goats has not been reported previously.

This lack of specificity means that the device detects some non-grazing activities as grazing activities. To study this confusion, several Lifecorder Plus devices were placed simultaneously in different locations on goats, and the signals from the neck and the legs (fore and hind) differed. Combining three Lifecorder Plus signals from the neck and the fore and hind legs would identify grazing periods better, because grazing seems to be defined mainly by head acceleration with little or no leg acceleration. One can assume that when Lifecorders on the neck and the legs have almost the same activity level, the goat is not grazing but probably walking or running. Placing even one additional Lifecorder Plus on one leg would thus increase the specificity by avoiding the confusion that occurs when the goat is walking or running for a long time outside of meals, which the Lifecorder Plus on the neck often identified as grazing (Figure 3). Goats can be active even when they are not grazing, unlike cows, which have clearly identifiable resting times (Delagarde and Lamberton, 2015). Goats are known for their dynamic behaviour, which differs from that of sheep (Miranda-de la Lama and Mattiello, 2010) or cows. Overall, goats are more reactive because they have more exploratory behaviours (Miranda-de la Lama and Mattiello, 2010). The Lifecorder Plus had high accuracy in this study probably because goats had access to small paddocks under rotational grazing management, and only during the daytime, which limited their walking time and other activities while at pasture. One can assume that a Lifecorder Plus on the neck would be less accurate when goats graze both day and night on large areas such as rangeland, desert or silvopastoral systems, particularly due to the long distances travelled each day (Vieira Costa et al., 2015; Paez Lama et al., 2021).

Under the conditions of this study, the Lifecorder Plus recorded the grazing time of goats correctly regardless of the individual goat, Lifecorder Plus device or sward height (in the typical range for vegetative pastures on farms), as no bias due to these parameters was identified. This result indicates a true utility for grazing research because it can measure grazing time accurately under a wide range of conditions. The goats must accelerate their head for the device to record grazing activities optimally, as indicated by differences in signals from the neck and the leg. Several observation periods during which goats grazed tall pasture at earing stage in a head-up position without accelerating their head clearly showed that the Lifecorder Plus did not detect grazing periods well in this situation. Similarly, the

Lifecorder Plus is probably not recommended in rangeland or agroforestry systems, where woody species prompt goats to browse in a head-up position.

5. Conclusion

The Lifecorder Plus can record the grazing time of dairy goats with high sensitivity, accuracy and precision in rotationally grazed vegetative temperate grasslands, with a low RPE of only 0.05. It overestimates actual grazing time slightly (< 3%), perhaps due to other active activities (e.g. running, walking, social activities) that it partly identifies as grazing. This small overestimate explains the device's lack of specificity. Nevertheless, it is sufficiently accurate to use in research on rotational grazing of goats under vegetative pasture conditions.

Conflict of interest

The authors declare no conflict of interest.

Acknowledgements

This study was partly funded by the French CASDAR project CAPHERB (no. 5546, Ministry of Agriculture and Food). The authors thank all staff of the Méjusseaume farm (PEGASE, INRAE, Institut Agro, 35750 Le Rheu, France) for milking, feeding and caring for the goats.

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Figure captions

Fig. 1. Examples of activity level recorded by the Lifecorder Plus device placed on the neck of goats at pasture (black horizontal lines) for 24-h periods. The goats were housed when not at pasture. The access time to pasture was 14, 11 and 8 h/d for a), b) and c), respectively.

Fig. 2. Frequency of activity level recorded during actual 2-min periods of grazing (●, n = 4629) or non-grazing (○, n = 964).

Fig. 3. Influence of the threshold value used to distinguish grazing activities (values greater than or equal to the threshold) and non-grazing activities (values lower than the threshold) on sensitivity (●), specificity (■), precision (□), accuracy (○) and relative prediction error (RPE) calculated at the scale of the hour (▲) or of the sequence (▼).

Fig. 4. Relationship between actual grazing time recorded visually by trained observers and grazing time recorded by the Lifecorder Plus device at each validation scale. The solid black line represents the 1:1 line (x = y).

Fig. 5. Relationship between the hourly bias in grazing time and the times of actual grazing, rumination, and other activities of dairy goats at pasture (187 h), and sward height (171 h).

Fig. 6. Activity level recorded by the Lifecorder Plus placed on the neck and the fore and hind legs for two additional recording sequences of two goats at pasture (two days independent of the validation dataset). The legs curve is the average between fore and hind legs curves because the signals were similar. For actual activities, only active behaviours (grazing, rumination, and other activities such as

walking, running or social interactions) are reported. The "blank" periods are resting time (no activity, no movement).

Table 1.

Distribution of experimental data used to validate the Lifecorder Plus device for grazing dairy goats.

Year	2015	2017	Total
Hour	16	171	187
Sequence	8	61	69
Date[a]	3	21	24
Day[b]	2	22	24
Goat	5	15	20
Lifecorder	4	9	12[c]

[a] Date: Number of calendar dates on which the observations were made
[b] Day: Standardised day of 8 h of recording
[c] One of the 12 Lifecorders was used in both 2015 and 2017

Table 2.

Mean and standard deviation of the duration of actual goat activities at each validation scale during the study (n = 11,186 min).

Validation scale	n	Average duration (min)	Grazing (min)	Rumination (min)	Other activities (min)
Hour	187	60	49 ± 13	2 ± 4	9 ± 12
Sequence	69	162	134 ± 58	5 ± 8	23 ± 25
Date	24	466	386 ± 172	14 ± 18	66 ± 54
Day	24	466	386 ± 81	14 ± 16	66 ± 52
Goat	20	559	463 ± 397	16 ± 18	80 ± 77
Lifecorder	12	932	772 ± 504	27 ± 19	133 ± 93

Table 3. Confusion matrix for the actual class (Observations) and predicted class (Lifecorder Plus), based on the number of 2-min periods (method 1).

	Observations		Total
Lifecorder Plus	Grazing	No grazing[1]	Lifecorder Plus
Grazing	4481 (True Positives)	260 (False Positives)	4741
Non-grazing[1]	149 (False Negatives)	704 (True Negatives)	852
Total Observations	4629	964	5593

[1] Non-grazing: Rumination + Other activities

Table 4. Accuracy of the Lifecorder Plus device for recording the grazing time of dairy goats at pasture at different scales of validation (method 2).

Validation scale	A[1]	P[2]	Regression of A on P				Bias[3]	MSPE[4]	Percentage of MSPE			MPE[5]	RPE[6]
			Origin	Slope	SD	R^2			Bias	Line	Random		
Hour	49.5	50.7	0.27	0.97	4.34	0.89	1.2	20.1	7	1	92	4.5	0.09
Sequence	134	137	-0.5	0.98	9.4	0.97	3.2	97.7	11	1	88	9.9	0.07
Date	385	395	6.1	0.96	18.8	0.99	9.3	458	19	10	71	21.4	0.06
Day	385	395	12.7	0.94	17.3	0.96	9.3	382	23	5	72	19.5	0.05
Goat	462	474	10	0.95	21.3	0.99	11.2	874	14	39	47	29.6	0.06
Lifecorder	771	790	3	0.97	25.3	0.99	18.7	1080	32	19	49	32.9	0.04

[1] A: Actual grazing time (min, observations)
[2] P: Predicted grazing time (min, Lifecorder Plus)
[3] Bias: (P-A)
[4] MSPE: Mean squared prediction error
[5] MPE: Mean prediction error (min)
[6] RPE: Relative prediction error

Validation of the Lifecorder Plus device for accurate recording of the grazing time of dairy goats

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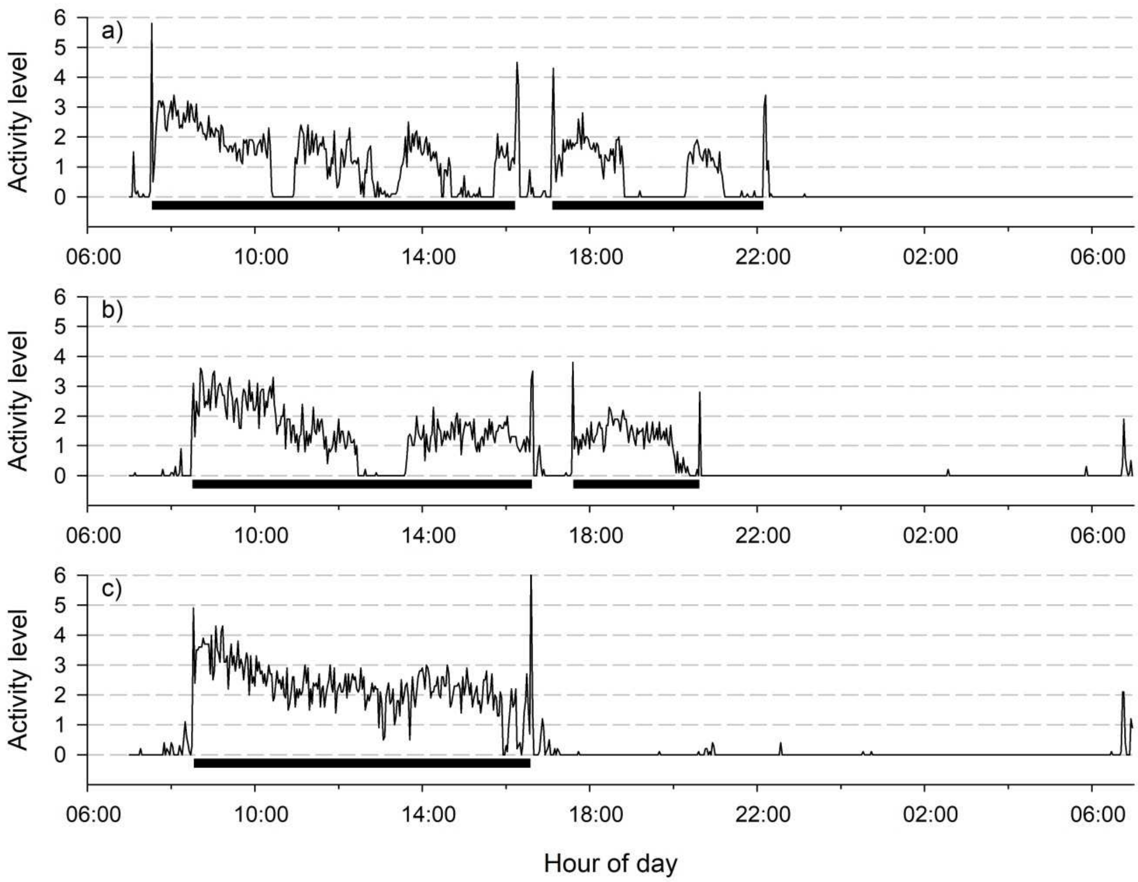


Fig. 1.

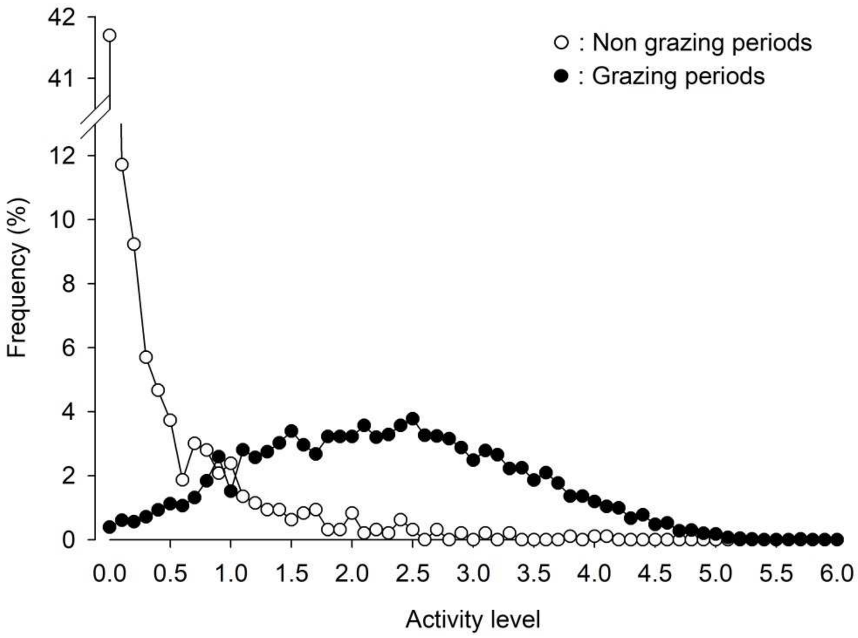

○ : Non grazing periods
● : Grazing periods
Frequency (%)
Activity level
42
41
12
10
8
6
4
2
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0

Fig. 2.

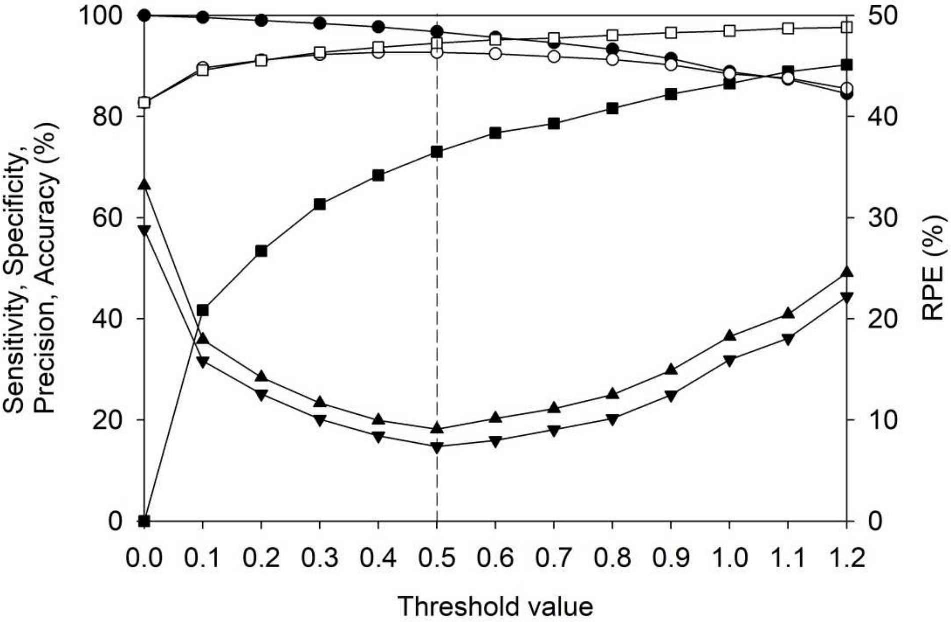

Sensitivity, Specificity,
Precision, Accuracy (%)
RPE (%)
Threshold value
0
20
40
60
80
100
0
10
20
30
40
50
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2

Fig. 3.

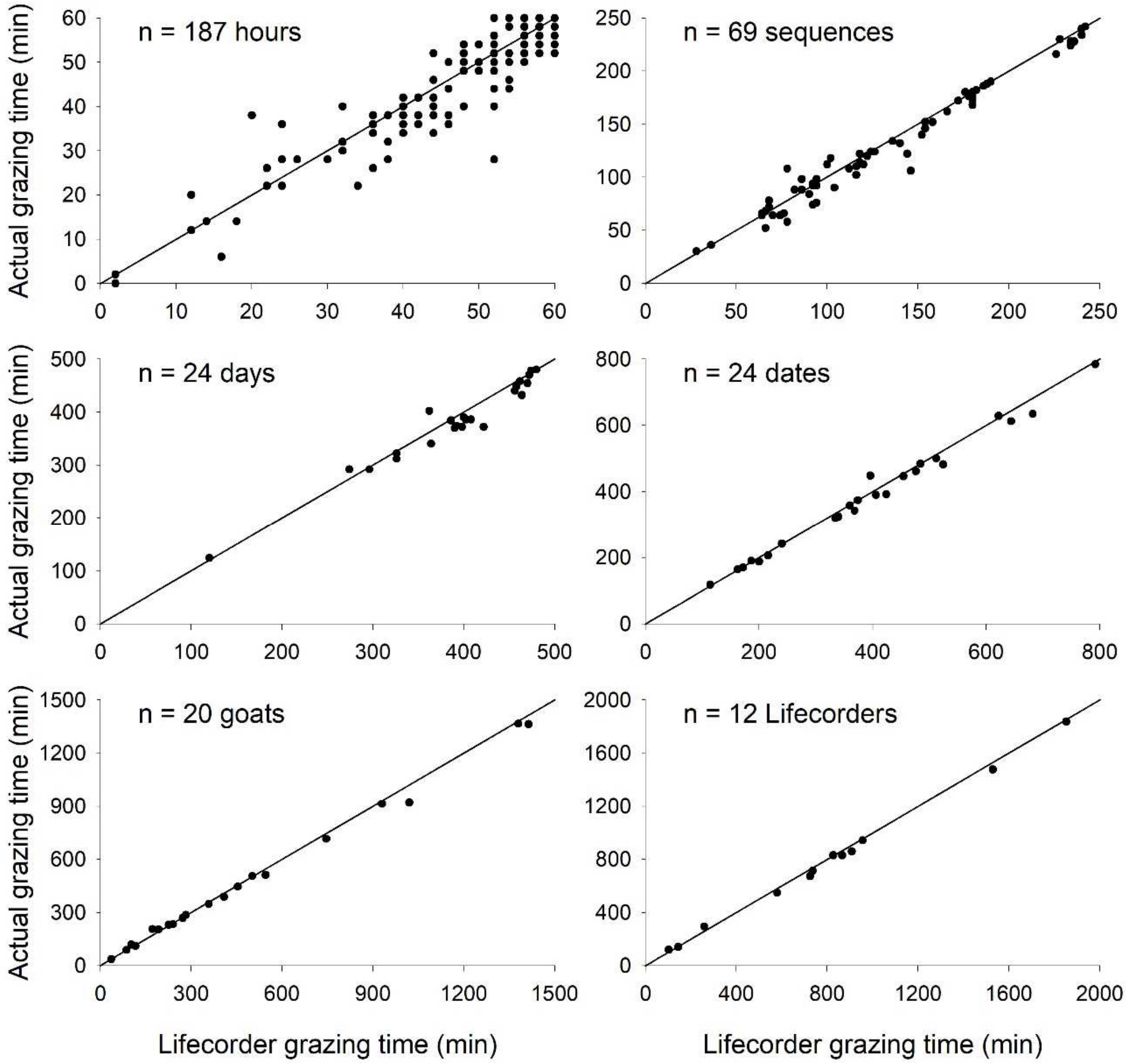
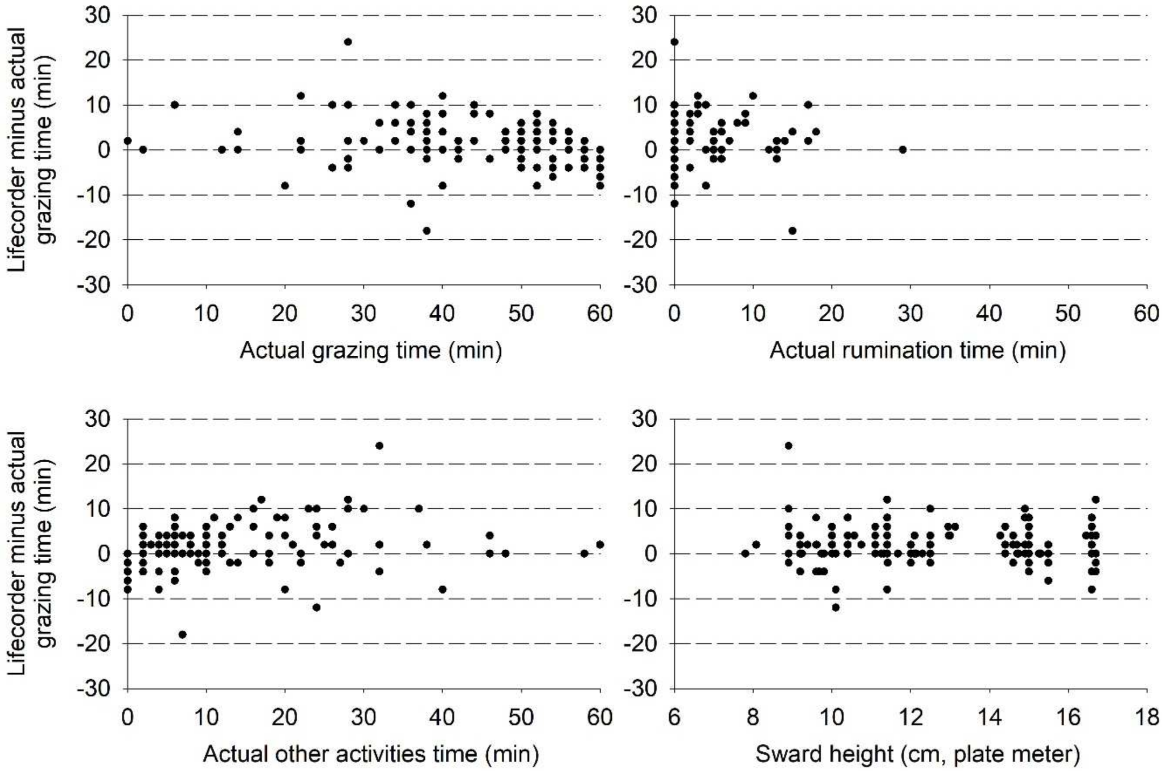
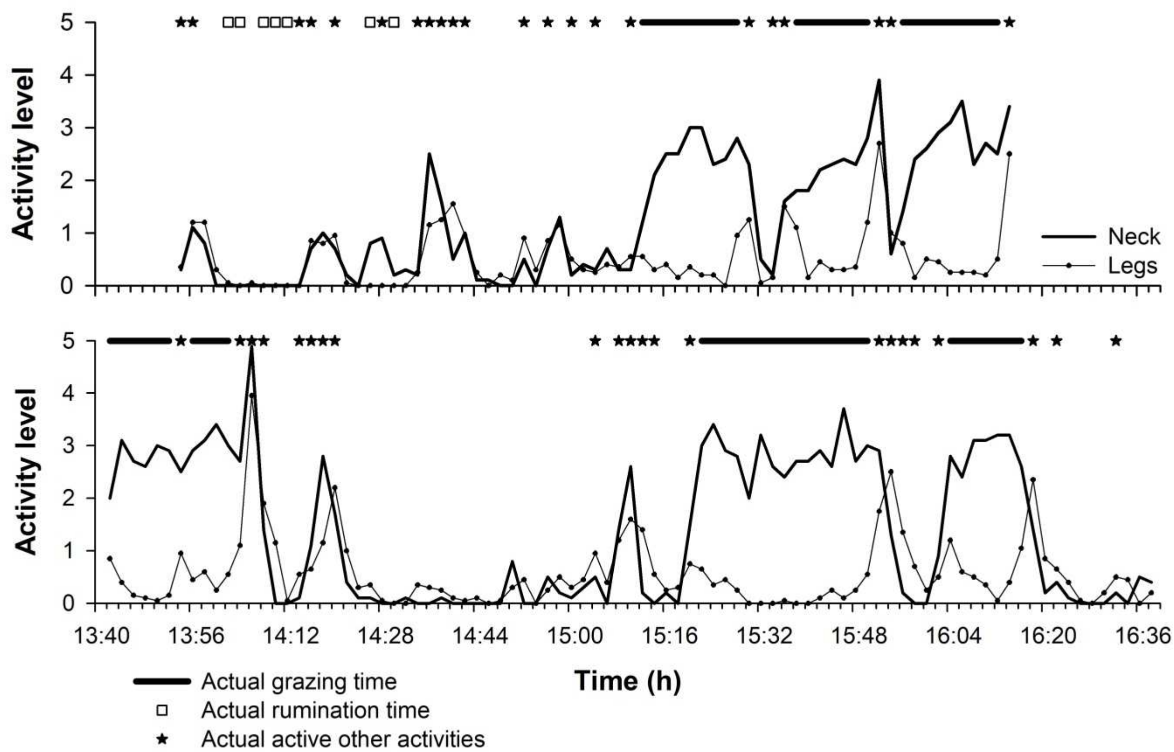

n = 187 hours
n = 69 sequences
n = 24 days
n = 24 dates
n = 20 goats
n = 12 Lifecorders
Actual grazing time (min)
Lifecorder grazing time (min)

Fig. 4.



Lifecorder minus actual grazing time (min)
Actual grazing time (min)
Actual rumination time (min)
Actual other activities time (min)
Sward height (cm, plate meter)

Fig. 5.



Activity level
Neck
Legs
Activity level
13:40
13:56
14:12
14:28
14:44
15:00
15:16
15:32
15:48
16:04
16:20
16:36
Time (h)
Actual grazing time
Actual rumination time
Actual active other activities

Fig. 6.