Changes in biting characteristics recorded using the inertial measurement unit of a smartphone reflect differences in sward attributes

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Abstract

Accurate monitoring of grazing activity at individual cow level would provide farmers with information which could be used to improve the management of their animals and pastures in intensive dairy systems. Pasture attributes, starting with sward height, influence grazing behaviour and bite characteristics. In an attempt to link sward height to automatic detection of biting behaviour in individual cows, a series of recording sessions lasting 4×3 days was conducted on a ryegrass pasture with two contrasting heights (5 and 15 cm) over the grazing season (from July to October) with 4 dry red-pied cows. The cows' behaviour was video recorded and each animal was equipped with the inertial measurement unit (IMU) of a smartphone on a halter, recording acceleration data at 100 Hz. Comparison of the video recordings with acceleration data showed that the number of grazing bouts during grazing tends to increase when the grass is taller. Fast Fourier transforms of acceleration data showed that grazing bouts were characterised by a distinctive acceleration peak with the frequency ranging between 1.02 Hz and 1.46 Hz whatever the sward height. Comparison with video recordings indicated that this value corresponded to the frequency of the specific movement for grass uprooting in the biting sequence. This peak could be used to improve automated grazing behaviour detection and to remotely characterise bites. These results show that some bite characteristics are influenced by sward height and automatic individual monitoring of grazing behaviour is possible. An extension of this methodology should allow deeper analysis of the grazing behaviour of cattle in order to remotely determine the number of bites and their specific patterns remotely and possibly to link this information to biomass intake.

Keywords: cattle behaviour, inertial measurement unit, bite frequency

Introduction

Recent developments in sensor technology have given rise to promising tools that will prove useful to farmers and contribute significantly to the coming of precision grazing management. Several studies demonstrate the capability of individual or combined sensors to classify and quantify animal behaviours. For example Martiskainen et al. (2009) equipped animals with a three-axis accelerometer and classified their behaviours by performing statistical analyses with support vector machines. More recently, Larson-Praplan et al. (2015) have studied cattle grazing strategies using global positioning sensors under different, seasonally contrasted environments.

Accurate monitoring of grazing and biting activity at individual cow level would be of considerable help as a means of improving animal performance and pasture management (Carvalho et al., 2015). The grazing mechanism is based on intensive jaw movements and is composed of 3 steps: prehension of the grass, uprooting of the grass and mastication before swallowing. This is the biting process (Gordon & Benvenutti, 2006). By counting bites, it is possible to determine their frequency which, combined with the weight of the bite (i.e. quantity of forage taken per bite) and the time spent grazing, allows calculation of grass intake (Vallentine, 2001). Moreover, continuous monitoring of the biting process is also a prerequisite for addressing the 'precision biting' issue, paving the way to precision grazing management (Carvalho et al., 2009).

Acceleration and gyroscope sensors are currently used in biomechanical studies to assess gait disturbance in humans (e.g. Leardini et al., 2014) and these sensors are used in the Inertial Measurement Unit (IMU) routinely fitted in smartphones to detect user-induced movements (Hazry et al., 2009). Since cattle move their body parts at a similar pace to humans, similar techniques could potentially be developed for fine analysis of movements on pasture. Andriamandroso et al. (2014) applied this idea and obtained promising results for automatic detection of grazing and ruminating behaviours using the iPhone 4S (Apple Inc., Cupertino, CA, USA), with accuracies ranging between 87% and 100%. The proposed detection algorithm determines head postures from the gravitational part of the acceleration (μ=[0.2g; 0.85g], 1g=9.81m.s^{-2}) and jaw movements from the acceleration transmitted by the cow on the IMU (σ=[0.0175g; 0.05g]) along the axis which is aligned with the anterioposterior axis of the animal's head. Taking this technique further, the aim of this study was to assess whether IMUs integrated into smartphones could provide information at the bite level when cattle are grazing pastures with different sward heights.

Material and methods

Data collection in the field

All experimental procedures performed on the animals were approved by the Committee for Animal Care of the University of Liège (Belgium). Four red-pied dry cows were fitted with a halter containing an iPhone 4S (Apple Inc., Cupertino, CA, USA). The mobile phones contained an IMU and signals from the 3D accelerometer, gyroscope and GPS were collected at 100 Hz using the Sensor Data application (Wavefront Labs, available on App Store, Apple Inc., Cupertino, CA, USA) for 9 hours from 8.00 a.m.to 5.00 p.m. each day.

The four cows wore the equipment for a 6-week familiarisation period and were then turned out to graze in one group on the experimental pasture in July-August and September-October 2014. The 1.8 ha pasture located on the Gembloux Agro-Bio Tech farm in Belgium (50° 33' 54.162" N, 4° 42' 7.945" E) consisted of newly established ryegrass and clover (*Lolium perenne*, 0.935; *Trifolium repens*, 0.065). The pasture was divided into different paddocks with different sward heights (5cm = low sward height – LSH, 15cm = high sward height – HSH) obtained by varying the post-mowing time from 7 to 21 days. The sward height and biomass availability were monitored before and after grazing by means of a rising-plate meter using in-house calibration. Each paddock was divided into 3 sub-paddocks, each providing approx. 80 kgDM.cow^{-1}.d^{-1}.

The animals grazed each sub-paddock for one day and were then moved to the next sub-paddock before 8.00 a.m. the next morning. The first day was removed from the database to allow the animals to adapt to the new sward height, while the second and third days were used for data collection and analysis.

Animals were continuously video recorded during all data collection days by two observers with one camera each. The two observers were assigned to two different cows simultaneously in sequences of 30 minutes, then the animals were swapped between observers. They focused on video recording of grazing and ruminating behaviours. The experimental scheme was as follows: 4 cows × 2 days × 2 sward heights × 2 grazing periods.

Data analysis

As the pasture height decreased quickly during the morning grazing, only the first 30 minutes were considered as typical for the given sward height. The video recordings were coded into a behaviour matrix using CowLog 2.0 (Hänninen & Pastell, 2009) with a specific focus on grazing behaviour.

Actual grazing bouts were visually analysed and jaw movements were counted and classified. A grazing bout was defined as an uninterrupted repetition of the sequence of grass prehension and uprooting, separated by mastication and swallowing. Two different analyses were performed on the collected data. Firstly, grazing bout duration ($y_{i,j}$) was compared by means of a general linear model in the MIXED procedure of SAS (Cary, NC, USA) where sward height (LSH and HSH), season (summer and autumn) and their interaction were used as mixed factors of variation. Individual cows were considered as experimental units.

Secondly, in order to allow a Fast Fourier Transform (FFT) of the signals, grazing bouts lasting less than 20 seconds were discarded as they did not allow further frequency-domain analysis as described below. The total number of grazing bouts (longer than 20 seconds) during the first 30 minutes of grazing varied between 11 and 24 bouts.cow^{-1}.d^{-1} for LSH and from 17 to 26 for HSH, expect when IMU signals were not properly acquired.

It was known that jaw movement patterns can be measured using the user acceleration on the x-axis of the IMU (Andriamandroso et al., 2014), and this signal was used to count each jaw movement within each grazing bout. For this purpose, the Periodogram function in Matlab R2014a (MathWorks, Natick, MA, USA) was performed for each individual bout on the user acceleration along the x-axis signal to identify possible frequency peaks. Finally, observed and detected movements for each grazing bout were compared in order to calculate detection errors.

Results and discussion

Effect of sward heights on duration of grazing bouts

No correlation was found between the influence of sward height and season on the parameters analysed. The duration of grazing bouts was shorter when cows grazed under HSH than LSH conditions ($p<0.01$) (Table 1) and detailed observation of video records showed that grazing bouts were separated by prolonged mastication and/or swallowing events. In addition, grazing bouts were shorter in summer than in autumn ($p<0.01$).

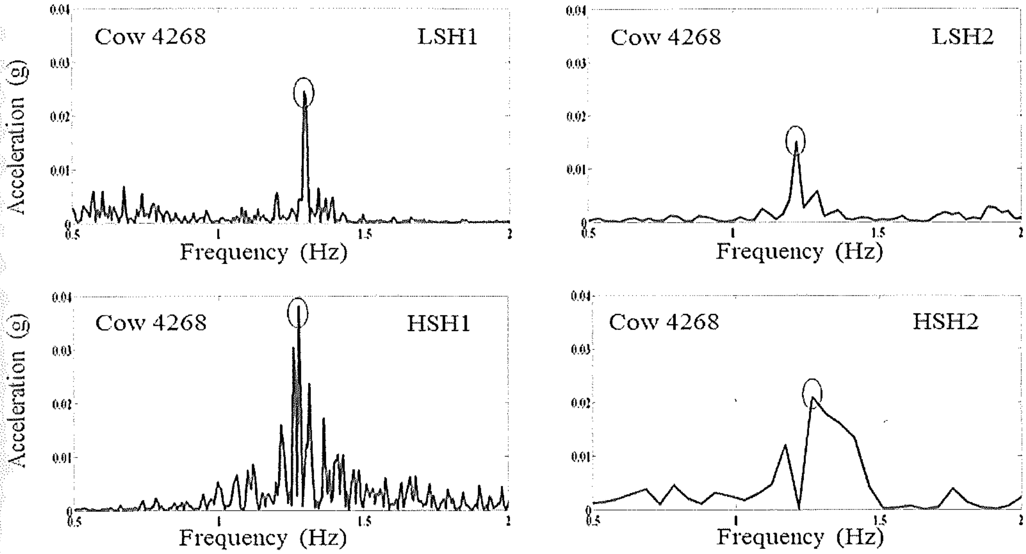
Table 1: Effect of sward height on grazing bout duration

Factor of variation	**Sward height**		**Season**	
	LSH	HSH	Summer	Autumn
Mean ± Standard dev.	$44.85 \pm 51.52^{a*}$	32.21 ± 32.66^{b}	31.37 ± 35.48^{b}	45.12 ± 47.44^{a}
Minimum	1	1	1	2
Median	29	20.50	19	30
Maximum	413	237	237	413

*For one factor of variation, means followed by different letters differ at a significance level of 0.05.

Detection of frequency peaks corresponding to uprooting bites

FFT analysis of the user acceleration signal along the x-axis (expressed in g, $1g=9.81 m.s^{-2}$) allowed us to identify a very distinctive repetitive peak between 1.02 Hz and 1.46 Hz within grazing bouts whatever the season and the grazing height (e.g. Figure 1). This signal corresponds to the movement transmitted along the anterioposterior axis of the animal's head. When compared with visual observations, the acceleration peaks exactly matched the frequency of uprooting jaw movements (uprooting bites) with a mean error of 4% to 5% (Figure 2 and Table 2). Sward height had no effect on the frequency of uprooting bites ($p=0.410$), probably because, in the range of sward heights used, the cows were able to adjust bite size to yield a constant grass DM intake per uprooting bite whatever the sward height (Carvalho et al., 2015). The frequency range observed here (60 to 88 uprooting bites.min^{-1}) was slightly higher than the bite frequencies of 30 to 70 bites.min^{-1} reported previously by Oudshoorn & Jorgensen (2013).



LSH1 and HSH1 for July/August 2014, LSH2 and HSH2 for September/October 2014

Figure 1: User acceleration on x-axis signal in the frequency domain for one cow

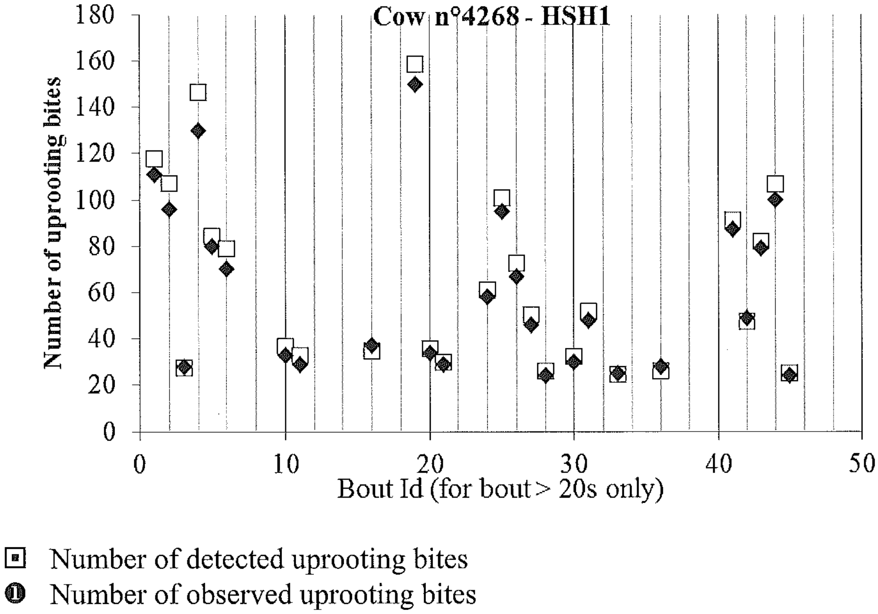


Figure 2 : Comparison of observed and automatically detected uprooting bites using the IMU signals within single grazing bouts for one cow grazing a high sward height pasture in August.

Detection errors were limited (Table 2). However, the number of uprooting bites was more often overestimated than underestimated when using the dominant peak in the frequency domain described above. A detailed observation of the video records for grazing bouts displaying this bias led us to hypothesise that some uprooting bites are not easily identified as such during visual observations. This visual misdetection might lead to lower counts of uprooting bites compared to acceleration-based counts. The observed differences between the present study and Oudshoorn & Jorgensen (2013) might also originate from the same bias, although other factors such as animal and grass characteristics might also explain why uprooting bite frequencies were higher in this study than in the previously reported work.

Table 2: Uprooting bite detection errors compared to visual observation

Sward height	Error min.	Error max.	Mean ± standard dev.
LSH1 (summer 2014)	0	9	5%±2%
LSH2 (autumn 2014)	0	16	4%±4%
HSH1 (summer 2014)	0	16	5%±5%
HSH2 (autumn 2014)	0	10	4%±2%

Conclusion

These results indicate that adding the frequency-domain peak analysis to the time-domain based Boolean algorithm for the detection of grazing behaviour proposed by Andriamandroso et al. (2014) could enhance its accuracy. This peak frequency range would be useful as a means of differentiating grazing from other behaviours performed with the same posture, such as drinking or looking for forage on the pasture. In addition, since contrasting sward heights produced easily detectable changes in grazing bouts, a deeper analysis of the length of the different phases within grazing bouts combined with bite weight measurements under contrasting pasture conditions might help in assessing the forage intake of ruminants on pasture.

References

Andriamandroso A.L.H., Dumont B., Lebeau F., Bindelle J., 2014. The performance of mobile devices' IMU for the detection of cattle's behaviors on pasture. *In: Proceedings of 12th International Conference on Precision Agriculture*, 20-23 July 2014, Sacramento, USA.

Carvalho P.C. de F., da Trindade J.K., Mezzalira J.C., Poli C.H.E.C., Nabinger C., Genro T., Gonda H., 2009. Do bocado ao pastoreio de precisão: compreendendo a interface planta-animal para explorer a multi-funcionalidade das pastagens. 46e Reunião Annual de Sociedade Brasileira de Zootecnia, Maringà, 2009.

Carvalho P.C. de F., Bremm C., Mezzalira J.C., Fonseca L., Trindade J.K., Bonnet O.J.F., Tischler M., Genro T.C.M., Nabinger C. & Laca E.A., 2015. Can animal performance be predicted from short term grazing processes ? *Animal Production Science* 55, 319-327.

Gordon I.J. & Benvenutti M., 2006. Food in 3D: How ruminant livestock interact with sown sward architecture at the bite scale. In: *Feeding in Domestic vertebrates: from Structure to behaviour*. (ed. Bell, V.), CABI, Publishing, Wallingford. 263-277.

Hänninen, L. & Pastell, M. 2009. CowLog: Open source software for coding behaviors from digital video. *Behavior Research Methods*. 41(2), 472-476.

Hazry D., Mohd Sofian M.R. & Zul Azfar A., 2009. Study of inertial measurement unit sensor. *In: Proceedings of the International Conference on Man-Machine Systems (ICoMMS), 11-13 October 2009*, Batu Ferringhi, Malaysia.

Larson-Praplan S., George M.R., Buckhouse J.C. & Laca E.A., 2015. Spatial and temporal domains of scale of grazing cattle. *Animal Production Science* 55, 284-297.

Leardini A., Lullini G., Giannini S., Berti L., Ortolani M. & Caravaggi P., 2014. Validation of the angular measurements of a new inertial-measurement-unit based rehabilitation system: comparison with state-of-the-art gait analysis. *Journal of neuroengineering and rehabilitation* 11, 1–7.

Martiskainen P., Järvinen M., Skön J.-P., Tiirikainen J., Kolehmainen M. & Mononen J., 2009. Cow behaviour pattern recognition using a three-dimensional accelerometer and support vector machines. *Applied Animal Behaviour Science* 119, 32–38.

Oudshoorn F.W. & Jorgensen O., 2013. Registration of cow bites based on three-axis accelerometer data. *In: Proceedings of the 6th European Conference on Precision Livestock Farming 2013 (EC-PLF), 10-12 September 2013,* Leuven, Belgium.

Vallentine J.F., 2001. *Grazing Management*. Burlington Academic Press Edition, San Francisco, CA. United States. 659 p.