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Original Article

Use of rumination and activity data as health status and performance indicators in beef cattle during the early fattening period

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Highlights

- Patterns of activity and rumination in beef cattle allow the detection of BRD and lameness
- Patterns of activity and rumination in beef cattle help in predicting average daily weight gain
- The use of individual sensors help in early diagnosis of cattle diseases, facilitating early and targeted therapies

Abstract

The aim of this study was to measure the level of activity and rumination in young bulls and to assess whether these data can be used as indicators of health status and average daily weight gain (ADG). Two groups of animals (period 1: n = 108 animals; period 2: n = 106 animals) were fitted with sensors to measure daily activity and rumination, were weighed on arrival and at the end of the trial (70 days) and were checked twice daily to verify their health condition. Any clinical signs and therapies were recorded. The dishomogeneity index of rumination (DR), and the daily dishomogeneity indices of activity (DDA) and rumination (DDR), were calculated. Bulls had an ADG of 1.42 ± 0.38 kg/day and showed an average duration of daily rumination of 404 ± 63 min and an average activity of 474 ± 46 bits, respectively. Animals characterised by low ADG had lower values of minimum daily rumination (*P* = 0.01) and DDA (*P* < 0.001), and a greater rumination range (*P* = 0.007) and DR (*P* = 0.003). Bovine respiratory disease and lameness were detected 31 and five times, respectively; among affected animals, the average daily activity, rumination and DDA were lower (*P* < 0.05) at 3-6 days before the onset of visible clinical signs, whereas DDR increased compared to the values when individuals were apparently healthy. The use of individual sensors appears promising for the early diagnosis of disease in beef cattle and for improving herd management.

Keywords: Beef cattle; Rumination; Activity; Growth; Bovine respiratory disease

Introduction

In the European Union (EU-28), the bovine meat sector produces 7.3 million tonnes of meat and represents 17% of total meat production[1]. Italy represents the fourth main contributor to the total bovine meat produced within the EU countries, preceded by France, Germany and the UK (Marquer et al., 2017)[2]; however, 43% of meat from cattle slaughtered in Italy is imported as young bulls and heifers (mean ± standard deviation 10 ± 2 months of age), mainly from France, to be grown and fattened in specialised fattening units mainly located in the north-eastern part of Italy (Cozzi, 2007). The imported bulls typically belong to French pure beef breeds (Charolais, Limousine, Blonde d'Aquitaine) or their crosses, typically weigh > 350 kg and are grown to 650-700 kg before being slaughtered after 6-7 months. They are mostly raised in roofed facilities, with littered or slatted floors, and fed rations based on maize silage and concentrates (Cozzi et al., 2009). After the arrival of the animals at the farm, there are four main feeding phases: backgrounding, transition, growing and finishing (Castillo-Lopez et al., 2014). These phases are necessary to ensure that animals can gradually adapt from diets based on forage to finishing diets that can contain up to 90% concentrates (Brown et al., 2006). This limits the risk of ruminal acidosis and provides the necessary energy and protein requirements for growth and marbling throughout the fattening cycle. In a fattening cycle of 6 months, backgrounding, transition, growing and finishing last approximately 35, 35, 60 and 60 days, respectively.

The first weeks after arrival at the fattening unit represent a crucial period for animal health and performance (Assié et al., 2009; Tennant et al., 2014). During this backgrounding period, animals must recover from the effects of stress due to transport and hierarchical competition, must get used to novel housing and feeding conditions, and will encounter microorganisms present in the new environment (Tennant et al., 2014). Together, these stressors increase susceptibility to diseases

[1] See: http://ec.europa.eu/eurostat/statistics-explained/index.php/Meat production statistics (accessed 25 June 2017).
[2] See: www.ismeamercati.it (accessed 25 June 2017).

(Taylor et al., 2010), particularly bovine respiratory disease (BRD), which is a major health problem in beef cattle worldwide (Gay and Barnouin, 2009). BRD is a multifactorial disease usually caused by concurrent viral (e.g. bovine respiratory syncytial virus, BRSV) and bacterial (e.g. *Mannheimia haemolytica*) infections and favoured by animal stress (Gay and Barnouin, 2009). Currently, the diagnosis of this disease is mainly based on visual detection of clinical signs, such as depression, respiratory signs and fever (White and Renter, 2009; Timsit et al., 2011). However, on large farms with hundreds or thousands of animals, these clinical signs are often hard to detect because of the limited time available for observing individual animals (Thompson et al., 2006; White and Renter, 2009).

On many farms, most diagnoses of BRD are carried out by farmers, while veterinarians are involved only in the most severe cases. This results in an underestimation of BRD cases, with a sensitivity that reaches at most 56% (Gay and Barnouin, 2009). Moreover, clinical signs do not appear immediately at the time of onset of the disease (Timsit et al., 2011); this interferes with early disease detection, which is critical in order to optimise the effectiveness of antibiotic and anti-inflammatory therapy (Humblet et al., 2004). To prevent the onset of BRD, in addition to vaccination, cattle are frequently subjected to metaphylactic treatments with long term antimicrobial agents (Tennant et al., 2014). This practice is both expensive and controversial because of the potential to promote antibiotic resistance (Duff and Galyean, 2007).

The use of devices able to detect animals early in the course of disease would facilitate timely diagnosis and subsequent individual therapy, without having to resort to metaphylaxis (Timsit et al, 2011). Continuous monitoring of behavioural and physiological parameters can aid early detection of sick animals, allowing immediate and targeted therapy (Weary et al., 2009). Timsit et al. (2011) detected BRD episodes using ruminal temperature. De Nardi et al. (2013) and Marchesini et al. (2013) used ruminal boluses to early detect ruminal acidosis. On dairy cattle farms, the use of individual sensors is increasing (Caja et al., 2016) for heat detection (Fricke et al., 2014) and the monitoring of ruminal activity (Schirmann et al., 2012) and other parameters; however, in beef cattle, the use of sensors is still relatively limited. In dairy cows, data on activity and rumination have been used to measure the effects of different rations on ruminal function (Adin et al., 2009) and have also been used to detect the early onset of mastitis (Stangaferro et al., 2016) and lameness (Van Hertem et al., 2013).

The aim of this study was to verify whether the application of sensors measuring activity and rumination could be useful in beef cattle during the early fattening phase (backgrounding and transition periods) for the detection of major health disorders, such as BRD and lameness. Such sensors, applied through a collar, have the advantage of being easily applied and can be reused. Moreover, since predicting the performance of animals could be useful to optimise management decisions from both logistical and economical perspectives (Galyean et al., 2014), we assessed whether activity and rumination data are indirectly related to average daily weight gain (ADG).

Materials and methods

Animals, housing, and feeding

This study was approved by the Organismo Preposto al Benessere Animale (OPBA) committee (approval number 13318; date of approval 28 January 2016). It was conducted on two groups of young Charolais bulls, bought at a cattle collection centre in France and selected based on weight, date of birth and physical conformation. They were imported from France by the same dealer in two periods: March-May (period 1/group 1; n = 108 animals) and August-October (period 2/group 2; n = 106 animals). The environmental temperature ranged from 5.7 to 27.0 °C in period 1 and from 13.0 to 31.2 °C in period 2, whereas the relative humidity ranged from 70 to 100% in period 1 and from 45 to 100% in period 2.

The animals were raised in a roofed, loose housing facility with straw bedding. Upon arrival, the bulls were on average 389 ± 47 (group 1) and 346 ± 80 (group 2) days old and weighed 453 ± 21 (group 1) and 429 ± 24 (group 2) kg. The trials each lasted 70 days, after which the animals were weighed before the beginning of the growing and finishing phases. The day after their arrival, the bulls were weighed in the early morning before feeding and grouped according to weight in 11 pens (9 or 10 animals per pen) with an individual space allowance of 7.0-7.8 squared metres each. They were vaccinated against infectious bovine rhinotracheitis (IBR), BRSV, parainfluenza 3 (PI-3) virus, bovine viral diarrhoea virus (BVDV), *M. haemolytica* and *Histophilus somnus*, treated for internal and external parasites (ivermectin and closantel), and fitted with SCR collars (HRLDn Tag; SCR Engineers) to measure their daily activity and rumination.

The SCR collars had an accelerometer that recorded the movements of the head and transmitted the data to a receiver connected to a computer at 2 h intervals. The software (Heatime Pro System/HRLDn Tag; SCR Engineers) discriminates among different type of movements and gives the rumination time and a level of activity from 0 to 253 bits (binary digit) per interval, indicating how much the animal has moved, but without specifying the type of action. Data were summarised on a daily basis. The system has been validated previously by other authors for both rumination and activity (Schirmann et al., 2009; 2012).

Upon arrival, the animals were fed a ration based on hay and maize silage for 3 days, followed by a total mixed ration (TMR) typically used in the backgrounding and transition phases in commercial farms; this included relative proportions of maize silage (2.5 kg), pressed beet pulps (2.6 kg), wheat bran (1.3 kg), maize meal (1.1 kg), soybean meal (0.5 kg), straw (0.6 kg), and a vitamin and mineral premix (0.58 kg), on a dry matter (DM) basis. The ration was gradually changed throughout the trial from an initial content of neutral detergent fibre (NDF), crude protein and starch of 37.0, 14.9 and 25.0% DM, respectively, to 35.0, 13.7 and 30.0% DM at the end of the trials.

Throughout the trials, the animals were fed ad libitum, and the amount of feed provided daily was adjusted to have leftovers equal to approximately 5% of the distributed ration. The TMR was distributed once daily in the morning, and there was unlimited access to fresh water.

Monitoring, clinical assessments and treatments

The animals were visually checked by trained farm personnel and by a veterinarian twice daily, at 9.00 h and at 18.00 h, to verify their health and the correct position of the collar. BRD was diagnosed when the rectal temperature was ≥ 39.7 °C (Timsit et al., 2011) in combination with one clinical sign of respiratory disease, including depression, nasal or ocular discharge, tachypnoea, dyspnoea or coughing. Animals diagnosed with BRD were treated with anti-inflammatory drugs (3 mg/kg ketoprofen once daily for 3 days) and antibiotics (20 mg/kg florfenicol repeated after 48 h) prescribed by the veterinarian. In cases of relapse, the veterinarian decided, on the basis of an antibiotic sensitivity test, whether to continue the initial therapy or whether to change medications. Sick animals that responded to the therapy were left in the pen; animals (3 bulls) that had more than one relapse were moved temporarily to the infirmary pen. Lameness, defined as an alteration of gait due to pain or discomfort from leg or hoof injuries or disorders (Van Hertem et al., 2013), was diagnosed by a veterinarian according to the Welfare Quality protocol for beef cattle[3]. Any clinical signs and therapies were recorded.

Statistical descriptors (minimum, average, maximum and range per day) and indices to describe the variation between consecutive values for activity and rumination data were calculated. Dishomogeneity indices within a day for activity (DDA) or for rumination (DDR) were calculated according to the following equation:

[3] See: http://www.welfarequalitynetwork.net/network/45848/7/0/40 (accessed 25 June 2017).

$$\text{DDA or DDR} = \frac{\sum_{i=1}^{n} |xi - x(i+1)|}{\sum_{i=1}^{n} xi}$$

where *i* is the number of 2 h intervals within a day (1-12) and *x* is the value of activity (bits) or rumination (min) measured in a 2 h interval *i* within a day. Dishomogeneity indices within the whole trial for activity (DA) or for rumination (DR) were calculated according to the following equation:

$$\text{DA or DR} = \frac{\sum_{i=1}^{n} |xi - x(i+1)|}{\sum_{i=1}^{n} xi}$$

where *i* is the number of days in the trial (1-70) and *x* is the value of activity (bits) or rumination (min) measured in a day *i* within the trial.

These indices have a range of values from 0 to 2 and showed how the activity and rumination varied within a day (DDA or DDR) or throughout the trial (DA or DR); a value of 0 indicates that there is no variation between different intervals, while a value of 2 indicates that there are one or more peaks of activity or rumination (Fig. 1).

Statistical analysis

Statistical analyses were conducted using SAS release 9.3 (IBM). Pearson's correlation coefficients (PROC CORR) were calculated between ADG and descriptors of activity and rumination. For statistical analysis, ADG data from period 1 (March) and period 2 (August) were grouped in three categories on the basis of tertiles distribution: low daily gain (LDG), medium daily gain (MDG) and high daily gain (HDG). Variables of activity and rumination were submitted to a two-way linear model (PROC GLM), including the fixed effects of period (period 1: March; period 2: August) and ADG (3 levels: LDG, MDG and HDG). The hypotheses of the linear models on residuals (normal distribution and independence) were assessed using the Shapiro-Wilk test (PROC UNIVARIATE).

To verify the usefulness of activity and rumination in identifying health status, a retrospective analysis of the data was performed. The data of the animals who were diagnosed with BRD or other health disorders that required pharmacological treatment (lameness) were selected and subjected to a mixed linear model (PROC MIXED) using the animal as a random and repeated effect, and the time from disease (TDD: 1, 0, -1, -2 and -3) as the main effect, where 0 is the period between the onset of clinical signs and the end of treatment, 1 is the period that precedes the disease by at least 9 days or the period after recovering, and -1, -2 and -3 are the periods that precede clinical signs by 1-3, 4-6 and 7-9 days, respectively. The activity and rumination values for each TDD category were calculated as the average of daily activity and rumination of each day belonging to the category. The 3 day interval for each TDD category (-1, -2 and -3), was chosen because both the activity and rumination have high fluctuations between one day and the next, and a 3-day interval was the most effective for discriminating between disease and health. In both models, post hoc pairwise comparisons among least square means were performed using the Bonferroni correction.

The percentage decrease in average daily activity, rumination and DDA, and the percentage increase in DDR found in animals at, or at least 1-3 days before, the onset of clinical signs were tested to evaluate their sensitivity and specificity in the early detection of BRD and lameness. The sensitivity and specificity were calculated as reported by Berkevens et al. (2006), taking into account the number of true positive (TP), false negative (FN), false positive (FP) and true negative (TN) cases, according the following formulae:

Sensitivity = TP/(TP+FN)

Specificity = TN/(TN+FP)

The total number of cases for both BRD and lameness were determined by multiplying the number of 3 day intervals of the trial (*n* = 23) by the number of animals that suffered BRD (*n* = 20) or lameness (*n* = 4).

Results

Statistics on ADG, rumination and activity in the two trials are reported in Table 1. Significant correlations with ADG were found for rumination range (RR), DR and DDA; *r* values were -0.47 ($P < 0.001$), -0.30 ($P < 0.001$) and 0.39 ($P < 0.001$), respectively. There was no significant effect of initial body weight on ADG. Among the categories of ADG, LDG was characterised by a significantly lower value of minimum daily rumination ($P < 0.05$) and a greater RR ($P < 0.05$) compared to other categories (Table 2). Animals with LDG also had greater variation in rumination between consecutive days (DR). Bulls with MDG had a greater average daily activity ($P < 0.05$) and DDA ($P < 0.05$).

In period 1 (March-May), BRD was diagnosed in two animals (1 episode each). In period 2, (August-October), 17 were animals diagnosed with BRD (27 episodes), three with lameness (3 episodes) and one with both BRD (2 episodes) and lameness (2 episodes). There were no episodes of diarrhoea or lethargy that would be indicative of the presence of ruminal acidosis (Nagaraja and Lechtenberg, 2007), although the presence of subacute ruminal acidosis was not investigated.

Cattle with BRD were treated for 4-19 days. Animals that experienced a single episode of BRD (which corresponds to animals treated for only 4 days) had a wide range of ADG and were distributed in all three categories of ADG, whereas animals with one or more relapses (animals treated for more than 4 days) had low weight gain and were primarily in the LDG category (Fig. 2). The BRD episodes were distributed throughout the trial, with three episodes in the first week (1 case in group 1 and 2 cases in group 2), 25 episodes from the third to seventh week (1 episode in group 1) and the last three at the end of the trial. All episodes of lameness were from the fifth to eighth week. Lame animals were treated with ketoprofen for 3 days according to veterinary prescription, and lameness did not affect ADG (Fig. 2).

Fig. 3 shows variations in activity and rumination which occur when an animal transitions from a healthy state to diseased state and then recovers. The average daily activity decreased by 7.3 and 11.5% 3 days before the onset of clinical signs and during treatment, respectively, when compared to that observed during health. Rumination was reduced as early as 6 days before disease diagnosis, decreasing 9.3 and 21.5%, 6 and 3 days before diagnosis and during treatment, respectively (Fig. 3a). A similar reduction in rumination (13.2%) occurred in DDA, starting at 3 days before clinical signs developed, whereas DDR increased by 16.4% (Fig. 3a).

These differences in daily activity, rumination, DDA and DDR between health and disease, were tested to verify their sensitivity and specificity for the early detection of BRD and lameness at least 1-3 days before the onset of clinical signs (Table 3). A 9% decrease in rumination (sensitivity = 0.81; specificity = 0.95) had the highest sensitivity for the early detection of BRD (*n* = 31 episodes in 20 animals), followed by a 13% reduction in DDA (sensitivity = 0.74; specificity = 0.97) and a 16% increase in DDR (sensitivity = 0.61; specificity = 0.96). A 9% decrease in rumination (sensitivity = 0.81; specificity = 0.95) had the highest sensitivity for the early detection of lameness (*n* = 5 episodes in 4 animals), followed by a 13% reduction in DDA (sensitivity = 0.80; specificity = 0.96) and a 16% increase in DDR (sensitivity = 0.80; specificity = 0.98).

Discussion

In this study, we examined whether it is possible identify sick beef cattle before the appearance of clinical signs and to predict production through the continuous monitoring of activity and rumination. Continuous monitoring of rumination and activity retrospectively allowed us to detect animals with BRD or lameness 3-6 days before the onset of clinical signs. The application of this technology to beef cattle farming would thus allow the timely application of proper treatment, potentially leading to faster recovery and reduced loss of production (Thompson et al., 2006), as well as more targeted use of antibiotics (Duff and Galyean, 2007). A 9% decrease in rumination had a sensitivity of 0.81 for the early detection of BRD; this is higher than a sensitivity of 0.58 for detection of clinical mastitis and equal to the sensitivity for detection of *E. coli* mastitis in dairy cows (Stangaferro et al., 2016). Although the specificity of the test would be considered to be acceptable, false positive should be taken into account to avoid unnecessary use of antibiotics.

The observation that animals with BRD show changes in activity and rumination 3-6 days before the onset of clinical signs is consistent with the findings of other studies using ruminoreticular temperature (Timsit et al., 2011) or infrared thermography (Schaefer et al., 2007) for detection of disease. In dairy cows, changes in patterns of activity and rumination during *E. coli* mastitis (Stangafferro et al., 2016) and lameness (Van Hertem et al., 2013) permitted the detection of affected animals 1-7 days before the onset of clinical signs.

The patterns of activity or rumination are described not only by how much time is spent on these activities, but also by how these activities are distributed over time, both on a daily basis or within the whole trial, and are summarised by the dishomogeneity indices DDA, DDR, DA and DR. The decrease in DDA and the increase in DDR 3 days before clinical signs indicate that the animal was not showing the usual peaks of activity and was ruminating erratically. Activity, rumination, DDA and DDR during treatment, the result of the average of the daily values of the period considered (from the first to the last day of treatment), were more similar to the values seen in the days before the onset of clinical signs than those found after full recovery.

The episodes of lameness led to changes in rumination and activity indistinguishable from those observed in BRD. This is probably because lame animals reduce their movement and the time spent feeding due to pain (Flower and Weary, 2006; Van Hertem et al., 2013). Sensitivity and specificity for the detection of lameness were higher than for BRD (1.00 and 0.96, respectively) when a 9% decrease in rumination was used as the criterion. These values are higher than those found for lameness in dairy cows (0.89 and 0.85, respectively) by Van Hertem et al. (2013), but they must be treated with caution, since they are based on only five cases of lameness.

The time that occurs between the arrival of the animals at the farm and the onset of the disease can affect the ability of the sensors to detect sick animals. In order to recognise a change in patterns of activity and rumination due to an episode of illness, it is necessary to compare the data with baseline values. In the present study, a disease episode could be detected when there was a significant variation in activity and rumination parameters compared to the period when the animal was healthy, which was established to be at least 9 days prior to the onset of clinical signs. If disease appeared before 9 of arrival, there would not be enough data to detect any variation of the parameters considered. To detect suspected cases of disease in the first few days after arrival, the data of each animal could be compared with the mean data of the group.

Although the correlation coefficients between ADG and rumination and activity patterns were low, they are similar to correlation coefficients between milk production and rumination time in dairy cows ($r = 0.42$) reported by Soriani et al. (2012). Beef cattle in our study showed irregular rumination patterns, with large variations between days; animals with high values of RR and DR were those with the lowest ADG. There are several possible causes of this variability, one of which is irregular feed intake (Watt et al., 2015). Rumination is also affected by the amount and length of the roughage fraction of the diet, and sorting behaviour (Gentry et al., 2016), and is positively correlated with dry matter intake (Watt et al., 2015). Mastitis (Stangaferro et al., 2016), lameness (Van Hertem et al., 2013) and heat stress (Soriani et al., 2013) are also associated with reduced rumination time and production, either directly or indirectly (e.g. reduced feed intake). In our study, animals that had a reduction in daily rumination to less than 180 min per day, even temporarily, had a high probability of being categorised as LDG. This may be due to alteration of the rumen microbial community (De Nardi et al., 2014, 2016).

The higher activity in animals belonging with MDG is not easy to explain, since activity represents the sum of a range of different behaviours, including eating, drinking, walking and social interactions (Weary et al., 2009). Almeida et al. (2008) observed that cows with lower than average levels of food intake and mastication spent more time on other activities, such as self-grooming. Animals that exhibited peaks of activity on a daily basis had a higher growth rate than animals with less variation in the level of activity within a day. These peaks of activity may coincide with the number of episodes of food intake each day, since a higher number of meals per day can improve rumen health and feed efficiency (DeVries et al., 2005).

Animals that were treated for more than 4 days, representing those with at least one relapse of BRD, were all classified in the LDG group. The bull that had the most relapses (n = 4) and was treated for 19 days (collar n. 74) lost 35 kg of body weight by the end of the trial. These data show that the BRD can be of importance from an economic point of view, because it entails additional costs for the purchase of medication, and in case of relapse leads to lower ADG and to depreciation of the carcass (Fulton et al., 2002).

Conclusions

The analysis of the patterns of activity and rumination in beef cattle during the conditioning period has proven extremely promising in allowing the detection of the animals early in the course of disease in the case of both BRD and lameness and identifying individuals that show low average daily weight gain. Although further studies are needed to explore the topic and confirm the promising results, tools that allow the continuous monitoring of rumination and activity can potentially help in the early diagnosis of common beef cattle diseases, facilitating early and targeted therapies, easing herd management and optimising performance.

Conflict of interest statement

SCR Engineers loaned the tags and the software used in this study. None of the authors have any financial or personal relationships that could inappropriately influence or bias the content of the paper.

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Figure legends

Fig. 1. Examples of patterns of activity and rumination in animals with the lowest and highest values of (a) dishomogeneity index of rumination (DR); and (b) daily dishomogeneity index of activity (DDA).

Fig. 2. Average daily weight gain (ADG) and treatment duration of animals in period 2 (n = 106). On the x-axis, bulls (identified by collar number) are sorted in ascending order of ADG and grouped into three categories according to ADG: low (LDG), medium (MDG) and high (HDG). The black line indicates ADG. The vertical bars indicate the duration of treatment received by sick animals in the case of bovine respiratory disease (BRD; n = 17, grey bars), lameness (n = 3, bars with diagonal lines) or both (bull number 30, black bar).

Fig. 3. Changes in daily activity patterns and rumination in cattle that developed bovine respiratory disease (BRD) or lameness during the study. The period preceding the onset of clinical signs is divided into intervals of 3 days each from 9 days prior to treatment. (a) Daily activity and rumination. (b) Daily dishomogeneity indexes of activity (DDA) and rumination (DDR). Means with different superscripted letters differ in activity ([a,b,c]) or rumination ([x,y,z]) at $P < 0.05$. Error bars indicate the standard error; in (b) the error bars are small and are masked by data markers.

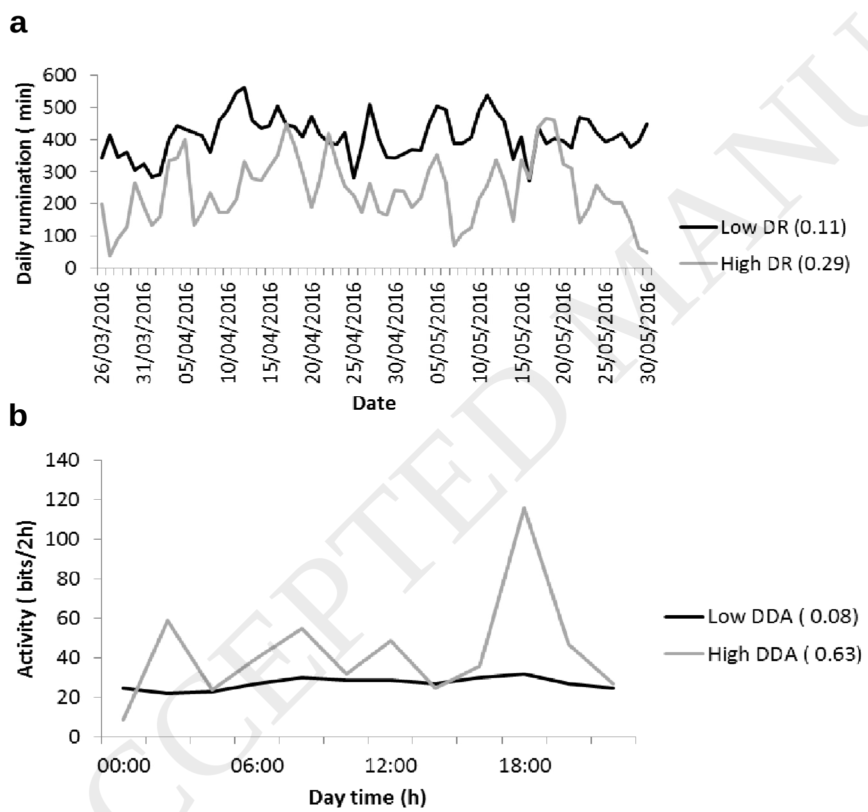

Fig. 1

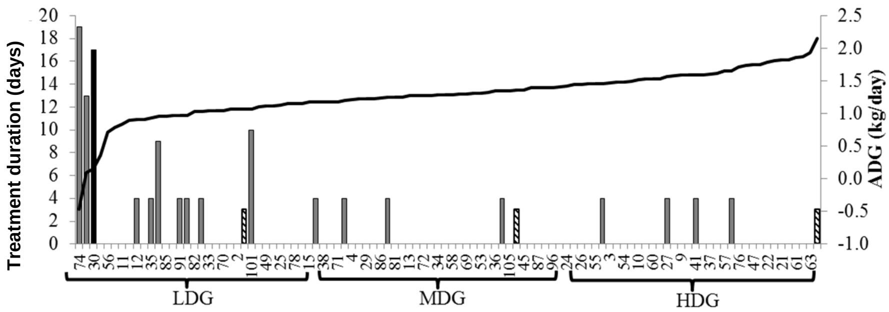
Treatment duration (days)
ADG (kg/day)
20
18
16
14
12
10
8
6
4
2
0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
74 30 56 11 12 35 85 91 82 33 70 2 101 49 25 78 15
38 71 4 29 86 81 13 72 34 58 69 53 36 105 45 87 96
24 26 55 3 54 10 60 27 9 41 37 57 76 47 22 21 61 63
LDG
MDG
HDG

Fig. 2

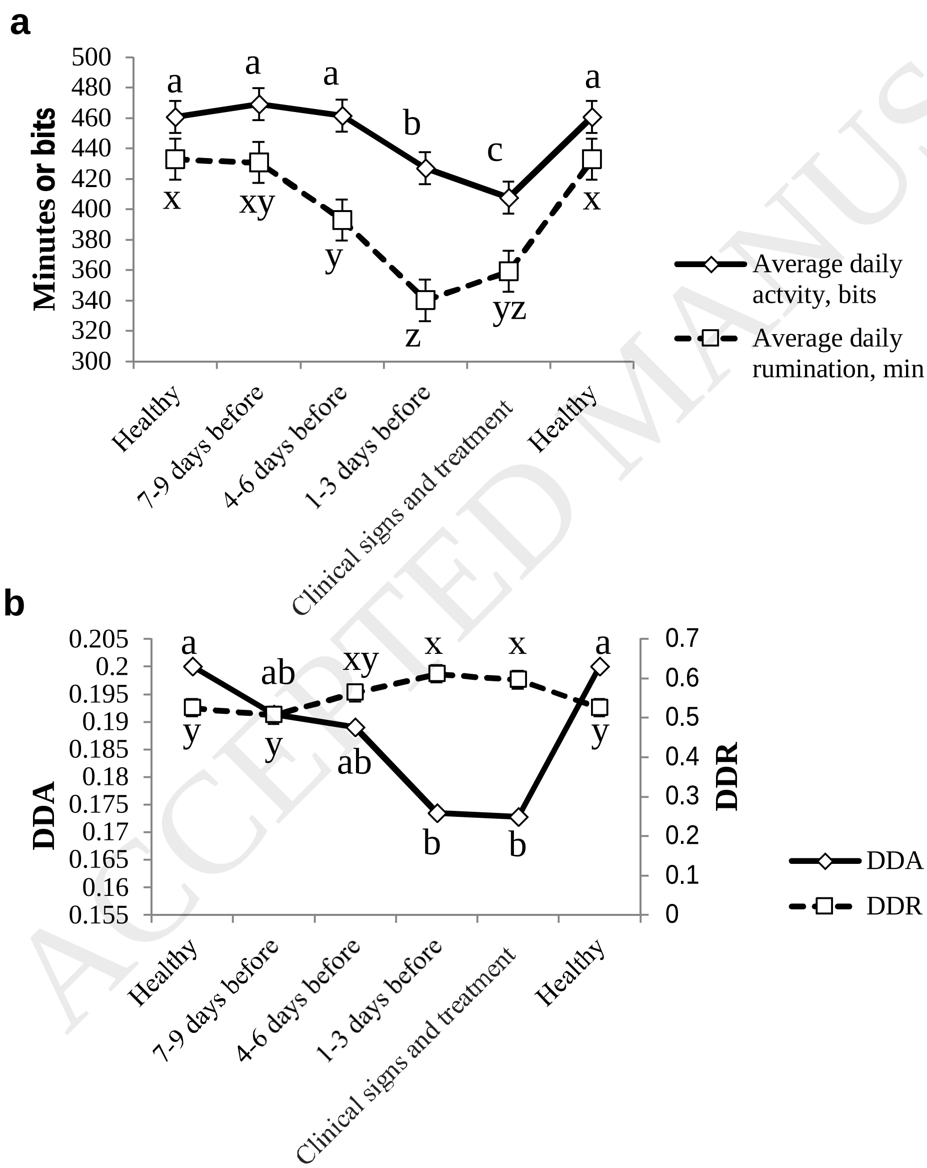
a
Minutes or bits
500
480
460
440
420
400
380
360
340
320
300
a
a
a
b
c
a
x
xy
y
z
yz
x
Average daily actvity, bits
Average daily rumination, min
Healthy
7-9 days before
4-6 days before
1-3 days before
Clinical signs and treatment
Healthy
b
DDA
DDR
0.205
0.2
0.195
0.19
0.185
0.18
0.175
0.17
0.165
0.16
0.155
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
a
ab
ab
b
b
a
y
y
xy
x
x
y
DDA
DDR
Healthy
7-9 days before
4-6 days before
1-3 days before
Clinical signs and treatment
Healthy

Fig. 3

Table 1
Average (mean ± standard deviation) rumination and activity data collected during the two periods (period 1: March-May; period 2: August-October).

	Mean ± Standard deviation		
	Average of the two periods	Period 1	Period 2
Average daily weight gain (kg)	1.42 ± 0.42	1.56 ± 0.31	1.28 ± 0.40
Average daily rumination (min)	404 ± 63	366 ± 50	443 ± 50
Maximum daily rumination (min)	573 ± 87	509 ± 56	639 ± 60
Minimum daily rumination (min)	181 ± 82	169 ± 82	194 ± 81
Average daily activity (bits)	474 ± 47	481 ± 51	466 ± 42
Maximum daily activity (bits)	634 ± 119	677 ± 130	590 ± 89
Minimum daily activity (bits)	364 ± 43	352 ± 42	377 ± 41

Table 2
Rumination and activity data according to average daily weight gain (ADG) categories.

	ADG			SEM	*P*
	LDG	MDG	HDG		
Rumination					
Average daily rumination (min)	394	410	412	6.20	0.087
Minimum daily rumination (min)	157 [b]	192 [a]	197 [a]	9.90	0.010
RR (min)	421 [a]	378 [b]	377 [b]	10.7	0.007
DR	0.184 [a]	0.167 [b]	0.162 [b]	0.005	0.003
DDR	0.576	0.567	0.566	0.009	0.69
Activity					
Average daily activity (bits)	464 [b]	484 [a]	473 [a,b]	5.70	0.043
DDA	0.314 [b]	0.353 [a]	0.325 [b]	0.007	0.001

LDG, low daily weight gain; MDG, medium daily weight gain; HDG, High daily weight gain; RR, rumination range; DR, dishomogeneity index of rumination; DDR, daily dishomogeneity index of rumination; DDA, daily dishomogeneity index of activity, SEM, standard error of means.
[a,b] Means with different letters within a row differ at $P < 0.05$.

Table 3
Sensitivity and specificity values of activity and rumination parameters used to early detect bovine respiratory disease (27 cases) and lameness (5 cases).

					Sensitivity		Specificity	
	TP	FN	FP	TN	TP/(TP+FN)	95% CI	TN/(TN+FP)	95% CI
Bovine respiratory disease								
Activity 7% decrease	12	15	7	449	0.44	0.40-0.49	0.98	0.97-0.99
Rumination 9% decrease	22	5	20	436	0.81	0.78-0.85	0.96	0.93-0.97
DDA 13% decrease	19	8	12	444	0.70	0.66-0.74	0.97	0.95-0.98
DDR 16% increase	16	11	15	441	0.59	0.55-0.64	0.97	0.95-0.98
Activity 11% decrease	7	20	3	453	0.26	0.22-0.30	0.99	0.98-1.00
Rumination 21% decrease	14	13	5	451	0.52	0.47-0.56	0.99	0.97-1.00
Rumination 17% decrease	16	11	9	447	0.55	0.51-0.60	0.98	0.96-0.99
Lameness								
Activity 7% decrease	3	2	1	86	0.60	0.49-0.70	0.99	0.93-1.0
Rumination 9% decrease	5	0	3	84	1.00	0.95-1.00	0.96	0.90-0.99
DDA 13% decrease	4	1	3	84	0.80	0.70-0.87	0.96	0.90-0.99
DDR 16% increase	4	1	2	85	0.80	0.70-0.87	0.98	0.91-0.99
Activity 11% decrease	3	2	1	86	0.60	0.49-0.70	0.99	0.93-1.00
Rumination 21% decrease	3	2	1	86	0.60	0.49-0.70	0.99	0.93-1.00
Rumination 17% decrease	4	1	1	86	0.80	0.70-0.87	0.99	0.93-1.00

TP, true positive cases; TN, true negative cases; FP, false positive cases; FN, false negative cases; daily dishomogeneity index of activity, DDA; daily dishomogeneity index of rumination, DDR; 95% CI, confidence interval at 0.95.
The differences found in daily activity, rumination, DDA and daily dishomogeneity index of rumination DDR between healthy and sick animals (Fig. 3) were tested to verify their sensitivity and specificity in the early detection of bovine respiratory disease and lameness at least 1-3 days before the onset of clinical signs.